TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

SECTION 13

GEOLOGIC HAZARDS

13.1 Introduction. The American Geological Institute (AGI) Glossary of Geology defines a geologic hazard as “a naturally occurring or man-made geologic condition or phenomenon that presents a risk or is a potential danger to life and property.” In this chapter these hazards are discussed as they pertain to Vandenberg and Edwards Air Force Bases, California; and Cape Canaveral, Florida. A section on seismic environment, prepared for space shuttle ground support equipment (GSE) design, has also been included.

13.2 Specific Hazards. Geologic hazards include: earthquakes, tsunamis and seiches, slope processes, floods, volcanic activity, expanding ground, and ground subsidence.

13.2.1 Earthquakes. Earthquakes are due to sudden releases of tectonic stresses which result in relative movement of rocks on opposite sides of a fault plane, as well as shaking of ground in areas near (and sometimes far from) the actual fault movement. Ground movement and shaking can trigger numerous other disasters, including landslides; liquefaction and sliding of unconsolidated sediments; destruction of buildings, dams, and roads; fires; tsunamis; seiches; changes in ground water level; and uplift of subsidence. They can also bring about far-reaching atmospheric pressure changes and sound waves and oscillations of the ionosphere (ref. 13.1).

Relative movement of different sections (plates) of the Earth’s crust causes stresses to build up near the boundaries between them. Movement along faults, releasing seismic waves, takes place when the effective stresses exceed either the strength of the solid rock or the frictional resistance between rocks on either side of a pre-existing break or fault. Since pre-existing fault surfaces usually have lower strength than the surrounding rock, movement takes place along them.

Many micro earthquakes take place along active faults, such as in parts of the San Andreas. But a greater number do not correspond to any known surface fault. Many of the earthquakes that are not associated with surface faults occur under folds—geologic structures formed when layered sediments are buckled upward in a broad arch called an anticline. The presence of an anticline reflects crustal compression as two moving tectonic plates collide, in the same way a carpet wrinkles when pushed across the floor. An unanswered question is whether these active folds conceal large faults, which could provide the sites for large shocks (ref. 13.2).

Earthquakes have proven to be one of the most disastrous and insurmountable of geologic hazards. Buildings constructed to withstand them have crumbled under their forces (ref. 13.1). Prediction of earthquake likelihood, intensity, and timing for a given location has not yet proved reliable (see subsection 13.2.1.1). Experience has shown that, to date, the best protection against earthquakes is identification of high-risk areas and avoidance of construction in them.

Definition of high-risk areas, a complicated process, includes mapping faults, dating movement on them to determine whether they are or might still be active, calculating theoretical maximum possible earthquake intensity for active faults, and predicting effects of possible earthquakes on sediments and rocks in the area. This information is then used to judge the safety of the area for construction.

Presented in figure 13.1 is a depiction of damaging earthquake potential occurring in the contiguous United States, based on where damaging earthquakes have occurred in the past. Five categories of damaging quakes are presented here, ranging from most damaging, indicated by the zone 4 to no major quakes, indicated by zone 0 (ref. 13.3a). The earthquakes that occurred in the Mississippi Valley (New Madrid) in late 1811 and early 1812 rank as the largest known shocks, with the largest potential damage and felt areas known, since the settlement of America began. An estimated area of 600,000 km^2 had potential damage of modified Mercalli intensity (MMI) equal to level VII or greater. The 1964 Alaska earthquake yielded a similar damage area of about 210,000 to 250,000 km^2, while the 1906 San Francisco earthquake had an area with MMI $\geq$ VII of about 30,000 km^2.

The Mississippi Valley map as presented in Figure 13.2 (ref. 13.3b) presents hypothetical maximum intensities (modified Mercalli intensity scale of 1931) that would result from a magnitude $M_S = 8.6$, maximum intensity $I_O = XI$, earthquake anywhere along the New Madrid seismic zone. Magnitude 8.6 was chosen because that is the estimated magnitude of the December 16, 1811, New Madrid earthquake. This composite intensity map shows a more widespread distribution of effects than would result from a single earthquake of magnitude 8.6 because the distributions of effects were plotted for magnitude 8.6 earthquakes that could occur anywhere from the northern to the southern end of the seismic zone, and the maximum of the resulting intensities was chosen for each point on the map. This composite intensity map is believed to represent the upper level of shaking likely to occur within this area regardless of the location of the epicenter within the seismic zone.

13.2.1.1 California Earthquakes. Since subsections 13.3 and 13.4 present and discuss earthquake and seismic activity potential related to the Edwards and Vandenberg Air Force Bases (AFB), California sites, it was felt appropriate that a brief general discussion on California earthquakes and predictions be given here.

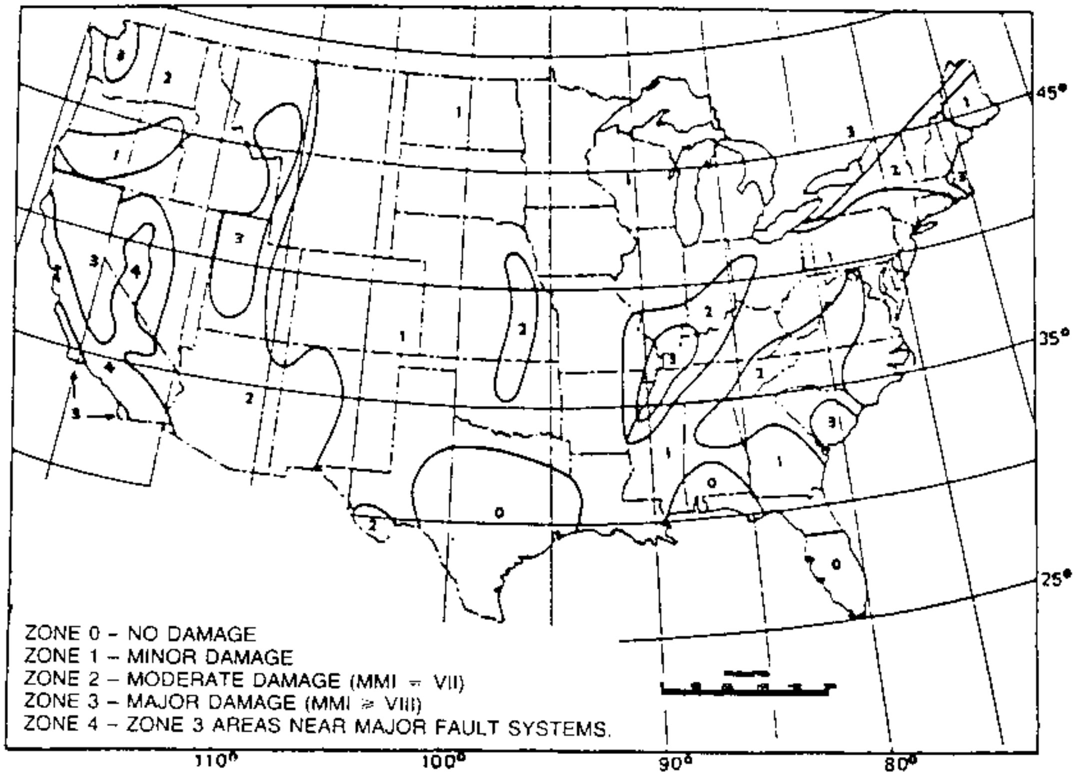


FIGURE 13.1 Seismic Risk Map of the Contiguous United States: Uniform Building Code, 1979 (Ref. 13.3a).

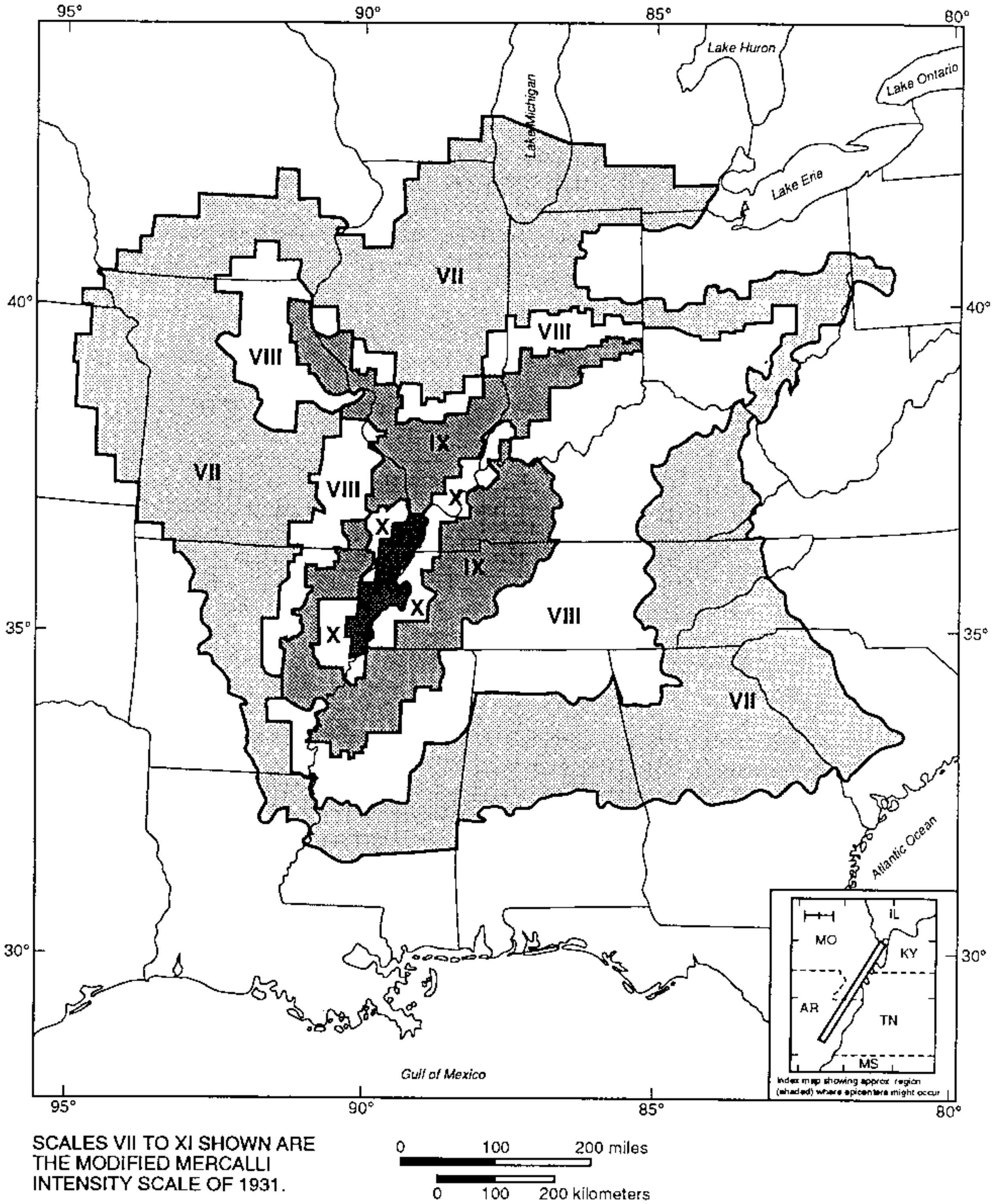


FIGURE 13.2 Estimated Maximum Regional Seismic Intensities Associated with Great Earthquakes that Could Occur Along the New Madrid Seismic Zone (Ref. 13.3b).

Between 1912 and 1984 there have been 38 recorded Southern California earthquakes with magnitudes of 6.0 or greater (ref. 13.4). Cousineau selectively lists 46 active and potentially active southern California faults which all have a maximum credible earthquake magnitude potential of 6.25 and higher. The San Andreas fault poses the greatest hazard to a NASA site from the standpoint of accelerations or shaking intensity. Detailed geologic studies indicate that this fault is likely to generate the largest earthquake of any fault in southern California and such an event is imminent (ref. 13.4).

Cousineau presents the work of Krinitizsky and Chang (ref. 13.5), in Figure 13.3a, in which western U.S. earthquakes have been analyzed relating intensity to epicentral distance over a range of earthquake magnitudes. Also presented in figure 13.3b is the relationship between fault length (length of surface rupture) and earthquake magnitude, based on the work of Bonilla (ref. 13.6) and then Greensfelder (ref. 13.7).

Preliminary ground motion statistics, i.e., horizontal accelerations and velocities in rock, caused by earthquakes for the contiguous United States are mapped and presented in reference 13.8 for exposure times of 10, 50, and 250 years at the 90-percent probability level.* The velocity and acceleration map for an exposure time period of 50 years at the 90-percent probability level is presented in figures 13.4 and 13.5, respectively. As more data becomes available, these statistical maps will be updated. The ground motion maps can be used mainly in building code applications, design of structures, and in land use planning. The associated velocity and acceleration attenuation curves versus distance for areas east and west of the Rocky Mountains are presented in figures 13.6 and 13.7, respectively (ref. 13.8).

Finally, the USGS Working Group on California Earthquake Probabilities (ref. 13.9) has recently published their first conditional probabilities (Fig. 13.8) for the occurrence of major earthquakes along the San Andreas fault between 1988 and 2018, with a 0.9 probability that the Parkfield, California, area will experience a significant earthquake before 1993. Since this publication, the San Francisco and Santa Cruz areas (Loma Prieta) experienced a magnitude 7.1 earthquake on October 17, 1989 (ref. 13.10). The USGF Working Group had assigned a 0.20 to 0.30 probability for major earthquake occurrence in the San Francisco area. An event of magnitude 7.5 or larger on the San Andreas fault is more likely in Southern California than in the northern part of the State. Such an event in the south could occur on the Carrizon, Mojave, San Bernardino Mountains, or Coachella Valley segments. The combined probability of an earthquake rupturing at least one of these segments in the next 30 years is 60 percent.

Fault rupture poses a threat to structures that cross active faults. History of actual fault breaks at the ground surface in southern California shows only 11 such breaks. In general, the locations of the surface breaks themselves are largely unpredictable except for those along the largest faults. In summary, there are considerably more active and potentially active faults than historic fault ruptures. The latter occurrence is rare but merits consideration, particularly if serious consequences of the break are possible (ref. 13.4).

*These map analyses of 1982 have been updated with velocity and acceleration plots being reissued in 1984 (ref. 13.8b).

13.2.2 Tsunamis and Seiches. Tsunamis are seismic sea waves. They can be generated by submarine earthquakes that suddenly elevate or lower portions of the sea floor, by submarine landslides, or by submarine volcanic eruptions. Tsunamis travel on the order of 500 km per hour and can cross an ocean in less than 1 day. Their wavelengths are long—100 to 200 km. Their amplitudes in deep water are low, less than 1 m, but as they approach a shoreline, their large volume of water piles up into sizable "tidal waves." Configuration of the shoreline and tidal and wind conditions can help to form waves over 10-m high. In 1948, the U.S. Coast and Geodetic Survey established a seismic sea wave warning system for the Pacific Ocean, so the arrival of tsunamis from distant sources can now be anticipated by a few hours.

A seiche is a long surface wavelength occurring in an enclosed body of water. Its period can vary from a few minutes to several hours and is very dependent on the dimensions of the basin, pond, lake, or enclosed bay. Commonly, seiches are low in amplitude and are not noticeable. When a large-scale disturbance takes place, however, larger amplitude waves result and can continue to be reflected back and forth across the body of water for hours or days. Large seiches can be caused when tsunamis arrive in bays, or when earthquakes and large slope movements initiate them in an enclosed body of water. Seiches can also cause the piling up of water at one end of a lake or bay, given the proper steady wind conditions acting on a large fetch area. Near enclosed bodies of water investigation of possible damaging seiche activity should be considered as a part of earthquake and slope movement studies.

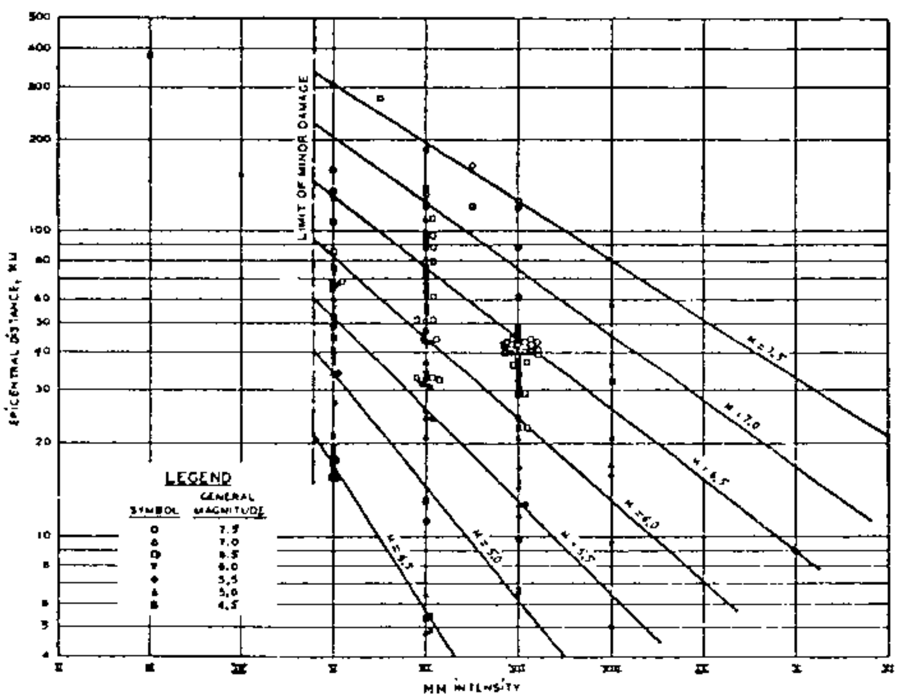


FIGURE 13.3a Intensity Versus Magnitude and Epicentral Distance (Ref. 13.4).

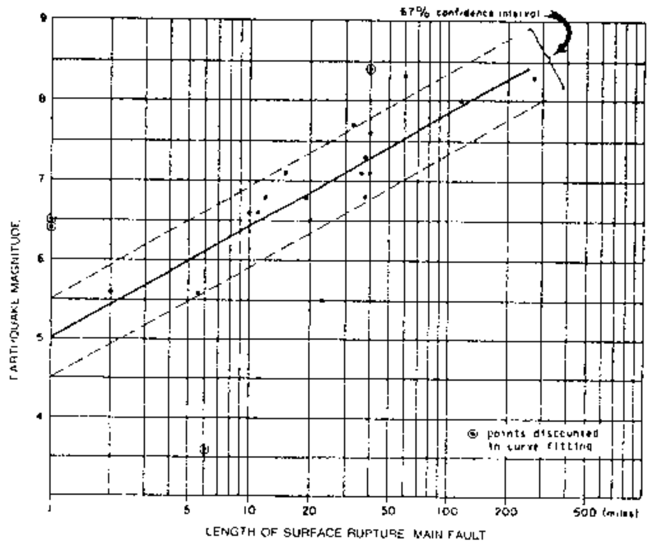


FIGURE 13.3b Earthquake Magnitude Versus Fault Rupture Length (Taken From Greensfelder, CDMG MS 23, 1974 (Ref. 13.4)).

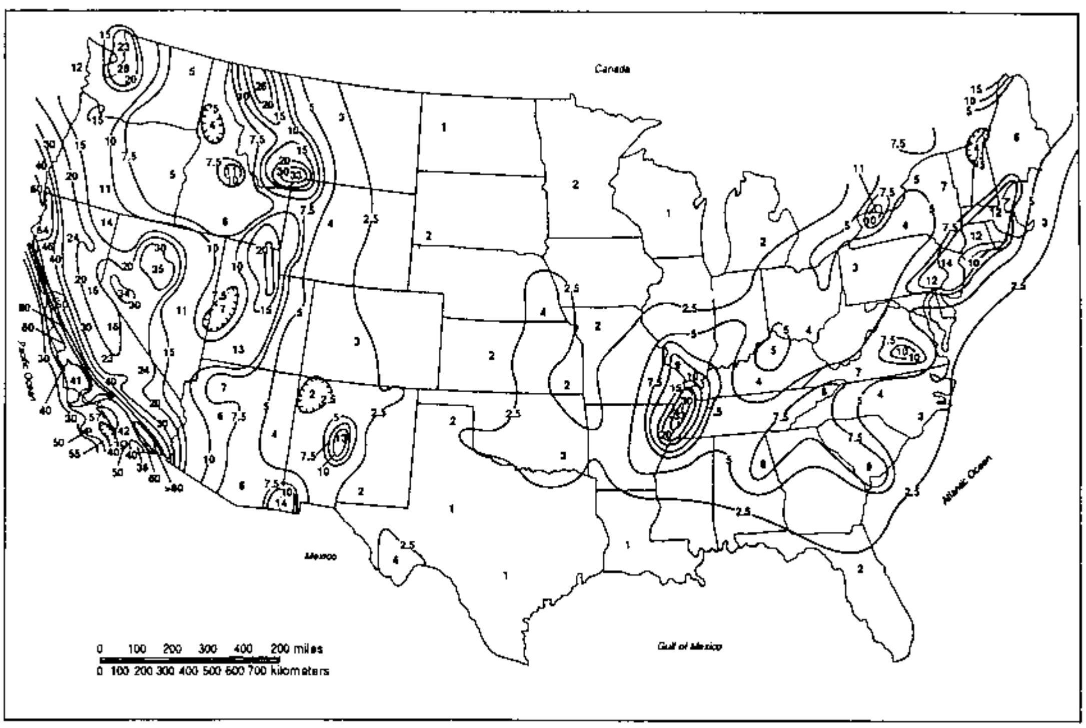


FIGURE 13.4 Preliminary Map of Horizontal Velocity (Expressed In cm/s) in Rock with 90-Percent Probability of Not Being Exceeded in 50 Years (Ref. 13.8b).

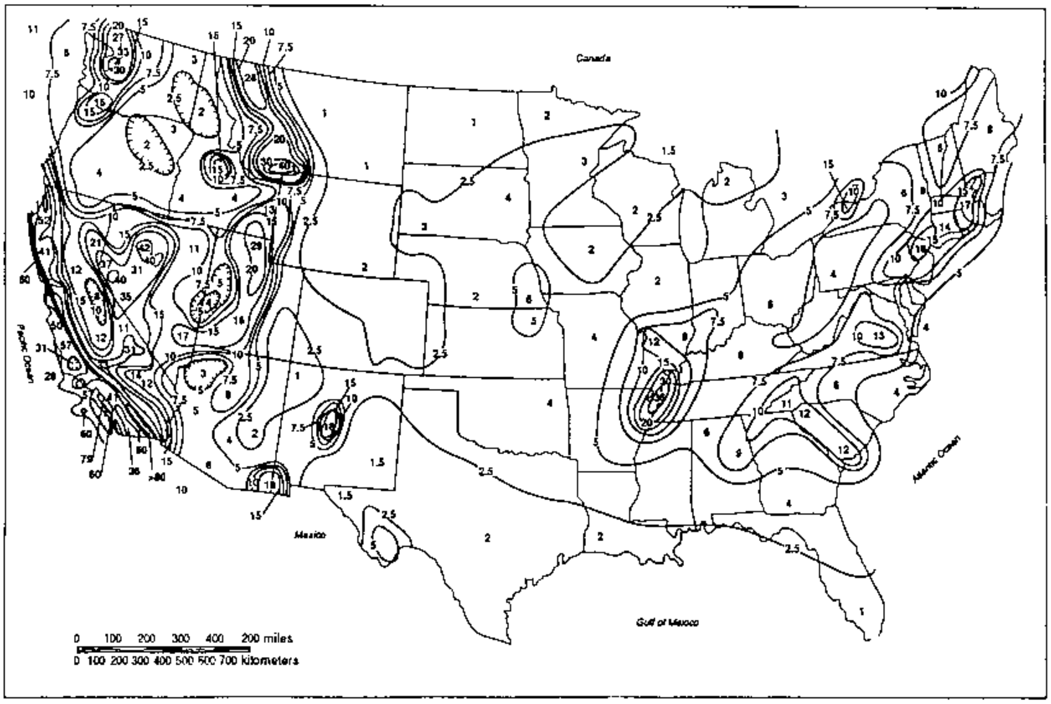
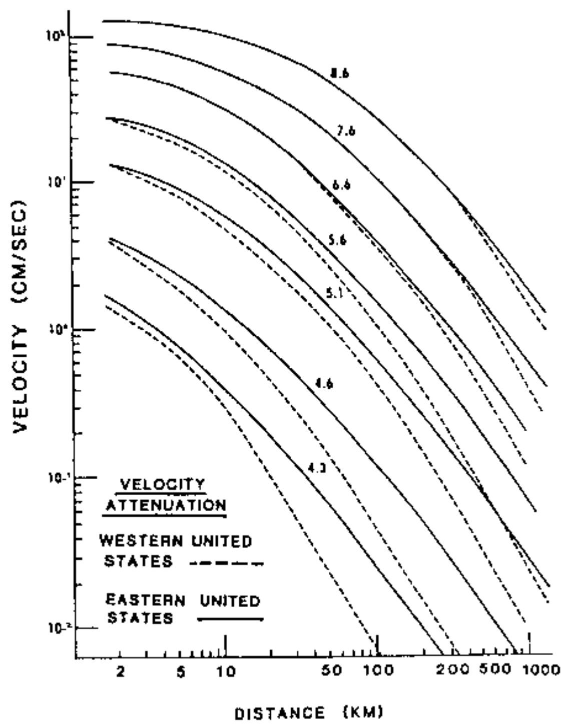
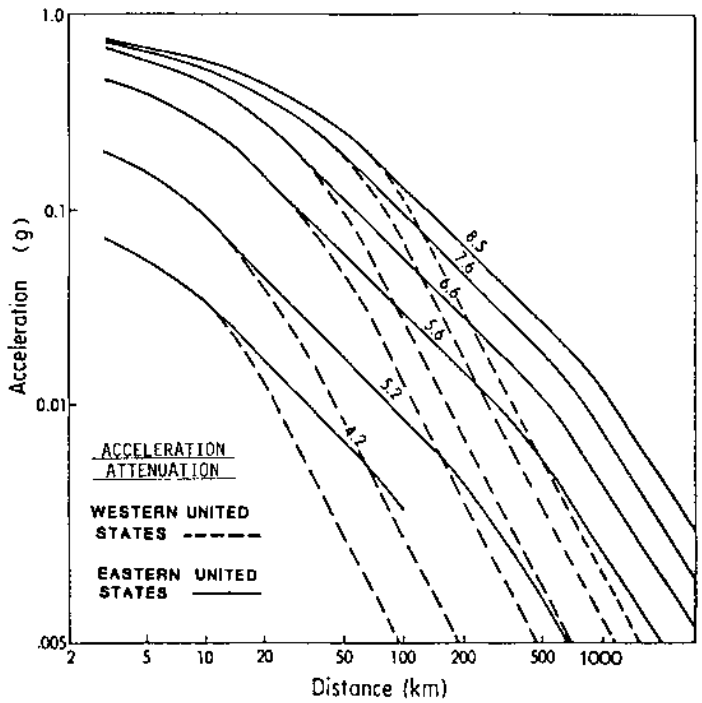


FIGURE 13.5 Preliminary Map of Horizontal Acceleration (Expressed as Percent of Gravity) in Rock with 90-Percent Probability of Not Being Exceeded in 50 Years (Ref. 13.8b).



The solid lines are curves used for the eastern region. The dashed lines together with solid lines (in some instances) at close distances are the attenuation curves used for the western region.

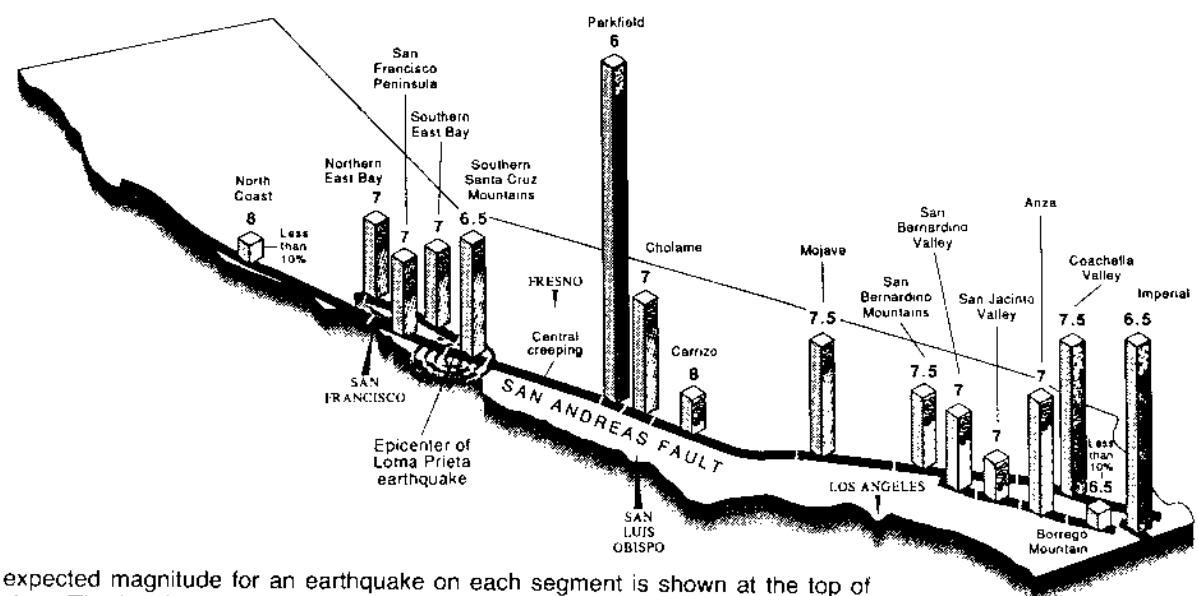
FIGURE 13.6 Velocity Attenuation Curves (Ref. 13.8a).



The solid lines are curves used for the eastern region (see text for definition). The dashed lines together with the solid lines at close distances are the attenuation curves used for the western region and are taken from Schnabel and Seed (1973).

FIGURE 13.7 Acceleration Attenuation Curves (Ref. 13.8a).

13-8



The expected magnitude for an earthquake on each segment is shown at the top of each box. The height of each box is proportional to the probability of the expected earthquake for that segment.

FIGURE 13.8 Conditional Probability of the Occurrence of Major Earthquakes Along the Four Major California Faults in the 30-Year Interval from 1988–2018 (Refs. 13.9, 13.10).

13.2.3 Slope Processes. Slope processes refer to all types of movement of loose or solid materials (soil and rock) on slopes. These processes range from imperceptible slow creep to land slide, rock-falls, and mud-flows which can travel more than 100 m per second. Mass movements are often seasonal or periodic, but they may be catastrophic or spasmodic. The nature of slope instabilities and resultant downslope transferences depend upon:

(1) Type and structure of materials, including composition, size of their particles, degree of consolidation, and structural discontinuities (cleavages, bedding, contacts, fractures, etc.).

(2) Geomorphic setting, including climate, vegetation, shape and degree of slope, and slope orientation.

(3) Triggering mechanisms, external factors which upset the delicate balance which maintains slope stability. These mechanisms include natural and man-caused activities such as earthquakes, explosions, addition of excessive fluids (especially water), and alteration of hillslope configuration (undercutting, etc.).

Tables 13.1a and 13.1b describe various types of mass movements, and figure 13.9 depicts several forms of this class of hazards (ref. 13.11).

Although some problem areas can be detected by examination of aerial photos, infrared photography, and topographic maps, potential-use areas should be examined on-site by competent engineering geologists and/or geotechnical engineers.

Historically, several methods of prevention and control of slope processes have been used with varying degrees of success. They are:

1. Avoidance of problem areas;
2. Water control (drains, surface water diversions);
3. Excavations (slope reduction, unloading, terracing, total removal of slides);
4. Restraining structures (walls, piles, bolts, grout, nets); and
5. Planting, effective only in controlling shallow, small-scale slope processes.

13.2.4 Floods. Floods are defined as “any relatively high streamflow which overtops the natural or artificial banks in any reach of the stream.” As a result, water and its sediment load are spread over the adjoining ground. Floods are natural, recurring events which become a problem only when they compete with man for the floodplain or flood channel. Rare catastrophic floods, in which water flows above and beyond the floodplains, may have disastrous consequences. Historically, catastrophic floods have resulted in loss of life and enormous property destruction. Initially, the greater than normal volumes of water, moving at abnormal velocities, are able to erode very quickly, picking up large volumes of sediment and debris. As water and its debris load continue downstream, large amounts of material (including man-made objects) are picked up or covered.

Floods normally occur as a result of cloudbursts, extended rain, and/or rapid snowmelt accompanied by rapid runoff. Natural dams such as those caused by landslide (as well as man-made dams) result in flooding of land upstream. Disastrous floods may also occur as a result of sudden release of large amounts of water by dam failures.

TABLE 13.1a Slope Processes.

Movement		Composition of Mass and Process			Favoring Conditions
Kind	Rate	Material dry or with minor ice or water	Material and water	Material and ice	
Creep	Very slow	Soil creep	Rock creep Talus creep	Solifluction	Unconsolidated sediment or structurally modified rock. Bedded or alternate resistant and weak beds. Rock broken by fractures, joints, etc. Slight to steep slopes. High daily and annual temperature ranges; high frequency of freeze and thaw; alternate abundant rainfall and dry periods. Balance of vegetation to inhibit runoff but not to anchor movable mass.
Flowage	Slow to rapid		Earth flow Mudflow Debris avalanche	Debris avalanche	Unconsolidated materials, weathering products; poorly consolidated rock. Alternate permeable and impermeable layers; fine-textured sediment on bedrock. Beds dipping from slight to steeper angles; beds fractured to induce water in cracks. Scarps and steep slopes well gullied. Alpine, humid temperature, semiarid climate. Absence of good vegetative cover such as forest.
Sliding	Slow to very rapid	Slump Debris slide Debris fall	Rockslide Rockfall		Inherently weak, poorly cemented rocks; unconsolidated sediments. One or more massive beds overlying weak beds; presence of one or more permeable beds; alternate competent and incompetent layers. Steep or moderate dips of rock structures; badly fractured rock; internal deforming stress unrelieved; undrained lenses of porous material. Scarps or steep slopes. Lack of retaining vegetation.
Subsidence	Slow to very rapid		Subsidence		Soluble rocks; fluent clays or quicksand; unconsolidated sediments or poorly lithified rocks; materials rich in organic matter, water, or oil. Permeable unconsolidated beds over fluent layers. Rocks crushed, fractured, faulted, jointed inducing good water circulation. Level or gently sloping surface.

Compiled and modified from Sharpe (13.12), by permission.

TABLE 13.1b Factors Causing Slope Processes.

Wedging and prying: by plant roots; swaying of trees and bushes in wind; expansion of freezing water and hydrostatic pressure of water in joints and cracks; diurnal, annual, irregular expansion due to heating; expansion due to wetting; animal activity. Filling and closing of cracks and voids caused by: burrowing of animals; decay of plant roots and other organic matter; gullying or undercutting by streams; removal of soluble rocks and minerals; erosion of fine particles by sheet wash and rills; downslope mass movement; shrinkage due to drying or cooling. Increase in load: addition of material upslope; rainfall, snow, or ice; traffic of vehicles or animals; tectonic, meteorologic, or animal disturbance.
Reduction in internal friction due to excessive amounts of water in mass. May start as slide; causes similar to landslides.
Removal of support: oversteepening of natural or artificial slopes by erosion; outflow, compaction, softening, burning out, solution, chemical alteration of subadjacent layer; disappearance of buttress against slope such as ice front. Overloading: by other mass-movement processes; by rain, snow, ice, and saturation, overburden in excavation. Reduction if internal friction and cohesion: by surface and ground water, oil seeps, chemical alteration by weathering. Wedging and prying: as in creep. Earth movement: produced by earthquakes; storms, traffic of vehicles and animals; drilling, blasting, gunfire, Earth strains due to temperature and atmospheric pressure and tidal pull.
Removal of support of adjacent layers: by solution or chemical alteration; by outflow of fluent material; by natural or artificial excavation; by compaction caused by natural or artificial overloading, by reduction of internal friction, by desiccation. Earth movement: by warping; by natural or artificially induced vibrations. Overloading: natural or artificial.

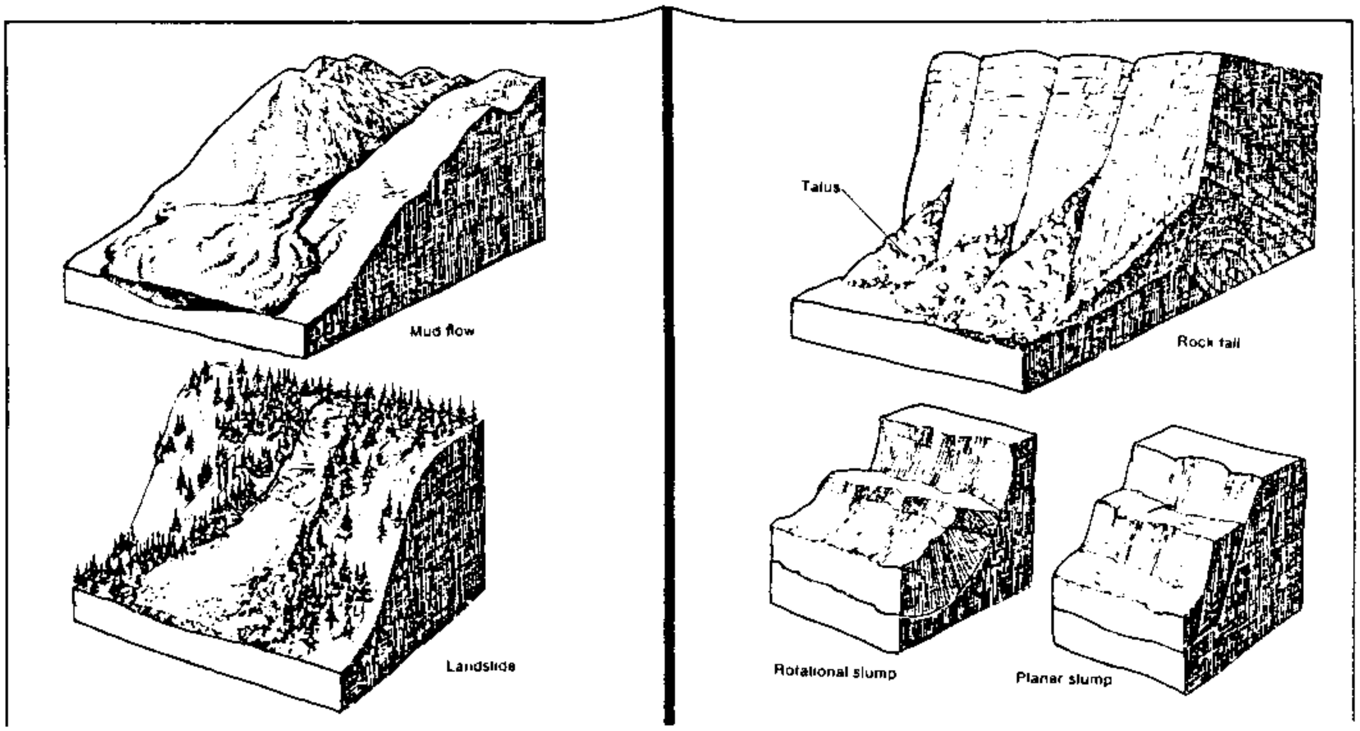


FIGURE 13.9 Illustrations of Slope Processes.

Several approaches have been used to avoid the damaging effects of floods. All these approaches make use of flood predictability from stream flow records and historical flooding recurrences. Flood hazard maps are compiled as various areas and assigned risk factors. The type of approach used to reduce flood damage will depend upon the calculated or assumed risk:

1. Avoidance of high-risk areas for construction activities.

2. Detention or delay of runoff in smaller tributaries at higher reaches of the watershed.

3. Modification of the lower reaches of rivers, where flood plain inundation is expected, by channels and levees.

13.2.5 Volcanic Hazards. Volcanic hazards fall into two categories: hazards near the volcanic activity and hazards distant from it (refs. 13.13 and 13.14).

13.2.5.1 Hazards Near Volcanic Activity. Within a few tens of miles of a volcanic center, hazards include: lava flows, nuées ardentes (hot ash flows) and poisonous gases, ash falls and bombs, earthquakes, debris, and mud flows.

1. Some lava flows are much more dangerous to man than others. Lava flows vary a great deal in viscosity, depending on their chemistry and temperature. They can be up to 10-m thick, travelling a meter per hour, or they can form a sheet as thin as 1 m which travels up to 50 km per hour. The latter have been the most hazardous to man in the past. A trained geologist can predict, to some extent, the type of flow most likely to occur in a given volcanic area. If fast fluid flows are likely, guiding levees can be built to shunt them away from populous or otherwise valuable areas.

2. Nuées ardentes are heavier than air, gas-borne flows of incandescent volcanic ash released during explosive volcanic eruptions. Temperatures in the flows reach 800° C, and the gases that carry them may be poisonous. These flows, though gas-borne, are extremely dense. Their physical force is great enough to snap large trees and crumble strong buildings. It was a nuée ardent from Mt. Pelée that devastated St. Pierre, Martinique, in 1902, completely destroying the town and killing an estimated 40,000 people. Hot, dense, poisonous gases can also be emitted without ash.

3. Ashfalls in the immediate vicinity of a volcano can be up to a few tens of meters deep and very hot. Near the eruption center they may contain sizable volcanic bombs of solid or solidifying rock, as well as pebble-sized fragments of pumice. They may give off gases for some time.

4. Earthquakes (see section 13.2.1) usually accompany volcanic activity and often trigger debris flows and mud flows.

5. Debris and mud flows form from the unconsolidated material that makes up the flanks of active stratovolcanoes. The material becomes unstable because of doming of the volcano, rapid melting of snow by hot ash or lava, and/or percolation of hot volcanic gases through snow masses. Volcanic mud and debris flows have been known to travel 80 km at speeds of several tens of km per hour. Some flows from major volcanoes contain on the order of 2 to 4 cubic kilometers of material. Dams in the paths of mud flow may break and contribute to the volume of flows that overtop them. In some places where mudslide hazard has been recognized, dams have been built and reservoirs kept empty to absorb them. In addition to downstream damage, volcano-caused landslides can cause instability at their point of origin: When a large volume of material is removed suddenly from the flank or summit of an active volcano, pressure is released and an eruption may be triggered (as in the May 18, 1980, eruption of Mt. St. Helens).

13.2.5.2 Hazards Distant from Volcanic Activity. Far from volcanic centers, volcanic ash and tsunamis can still be serious hazards.

1. An ashfall's total volume depends on the size of the eruption that brought it about. Its distribution depends on the elevation reached by the volcanic cloud and on wind conditions at the time of the eruption. A sizable ashfall can damage areas several hundred kilometers from the eruption site. Ash is detrimental to human health and damaging to mechanical equipment. It reduces visibility if there is wind or traffic, and must be removed from buildings and pavement. Fine ash, if it reaches the stratosphere, may remain there for months or years, affecting climate by reducing insolation. See section 10 concerning aerosols in the atmosphere.

2. Tsunamis (see section 13.2.2) may be caused by submarine volcanic explosions and debris slides, which can travel thousands of kilometers from the volcanism that caused them. They endanger life and all coastal construction within 40 m of sea level.

When considering volcanic hazards, it is important to realize that in any area volcanism is sporadic. A volcanic area which has been inactive throughout historic times may reawaken to violent activity in a few days or weeks, or it may remain inactive for centuries into the future. Earthquakes, almost always felt or recorded several days or weeks before activity commences, serve as a warning of impending danger. Once volcanism commences, danger is greatest within a few tens of kilometers of the eruption. The effects of volcanism can easily be catastrophic, especially since volcanoes are virtually uncontrollable by man. Important constructions should not be located in the immediate vicinity of active or dormant volcanoes, or in areas likely to be affected by distant volcanism.

13.2.6 Expanding Ground. Expanding ground is caused by freezing and/or expansive soil or anhydrous expansion (without freezing) of moisture in the ground or by rock components that expand when wet. Expansive soils are found throughout the U.S. The soil can increase its volume as high as 1,000 percent if it is allowed to. The actual expansion depends upon the amount of water available and the overburden on the soil. The process of the expansion is generally slow. The heaving force can cause serious damages to foundations and structures.

When water freezes, its volume increases by approximately 9 percent. When water in fine-grained, unconsolidated material freezes, additional water from the atmosphere and from unfrozen ground below slowly adds to the already frozen mass. Eventually, lenses of ice build up, lifting the soil above them. In areas where winters are cold and moist, or where day-night temperatures differ markedly, freezing and thawing may cause marked dislocation of surface and near-surface materials. Some clays contain minerals that increase in volume upon wetting and decrease in volume upon drying. The most common of these minerals are anhydrite and of the montomorillonite clay group. Problems with expansive clays and the rocks and soil in which they occur are most frequently encountered in arid or semiarid areas with strong seasonal changes in soil moisture.

Expansive clays are particularly associated with volcanically derived materials. Shales containing clays of the montomorillonite group (including bentonite derived from volcanic ash) commonly swell 25 to 50 percent in volume (ref. 13.15). Such swelling results from chemical attraction of water molecules and their subsequent incorporation between submicroscopic, platelike clay molecules. As more water becomes available, it infiltrates between the clay plates and, with freezing, pushes them farther apart. Similarly, hydration of the mineral anhydrite induces a chemical change, causing 40 percent expansion and altering the anhydrite to the mineral gypsum.

These large increases in volume upon freezing or hydration, and associated decreases in volume with thawing or drying, can be very destructive. Volume increases of only 3 percent are considered to be potentially damaging and to require specially designed foundations. James and Holtz (ref. 13.16) report that shrinking and swelling damage to foundations, roads, and pipelines in the United States amounts to more than twice the dollar value of damage incurred by floods, hurricanes, tornadoes, and earthquakes combined.

On-site inspection by a competent soil engineer or engineering geologist may pinpoint potential clay-expansion problems. Engineering soil tests are required to evaluate the extent and severity of the problem in construction sites.

Installation of well-designed drainage systems using chemical treatment, or complete removal of expansive materials, may lessen the potential damage from expansive ground.

13.2.7 Ground Subsidence. Ground subsidence is characterized by downward movement of surface material, caused by natural phenomena such as removal of underground fluid, consolidation, burning of coal seams, or dissolution of underground materials. It may also be caused by man's removal or compaction of Earth materials.

Ground subsidence is ordinarily a relatively slow process; it has been known to continue for many decades. Usually the result is broad warping and flexing, with some cracking and offset at the ground surface. If the process causing subsidence persists, the surface may suddenly collapse. Foundation failures, ruptures of pipe and utility lines, dam collapses, salt water invasion, and disruption of roads and canals have all been directly attributable to ground subsidence.

Potential causes for ground subsidence include:

1. Removal of solids: Removal of the solid subsurface support base involves mining, natural or human solution of carbonate and other easily soluble minerals (including salt and sulfur), and underground burning of organic beds. Cavern collapse is the most catastrophic result. Alternatives to avoiding such areas for heavy loads include subsurface backfilling, cement-grouting, and installation of underground support pillars.

2. Withdrawal of fluids: Subsidence due to withdrawal of fluids (including gas, oil, and water) is the most common type of man-caused regional ground subsidence. As fluids are removed, and fluid pressure within the aquifer or reservoir rock is reduced, the aquifer skeleton must bear an increased grain-to-grain load. In permeable media, the increase in effective stress and subsequent compaction is immediate. Increasing percentages of clays in the aquifer cause the adjustment to take place more slowly. In extreme cases, subsidence of more than 7 m over a 60-year period has been directly attributed to withdrawal of water and/or petroleum. Injection of fluids back into the aquifer might arrest the subsidence.

3. Oxidation of organic beds: Oxidation of organic beds, such as layers of peat, and resultant breakdown of support structures have been known to follow drainage of peat bogs. Raising the water table can inhibit this oxidation.

4. Application of surface loads: Compaction due to surface loading alone commonly results in only minor ground subsidence. However, application of surface loads may trigger more severe subsidence when added to already weakened substratum conditions.

5. Hydrocompaction: Wetting of some clays in moisture-deficient, low-density soils may lead to weakening of clay bonds which support soil voids, and ultimately to collapse of internal soil structure and compaction. Hydrocompaction commonly occurs in wind-deposited silts and fine-grained colluvial soils which have a high clay content. Some areas near the south and west borders of the San Joaquin Valley dropped 1.5 to 5 m in the early 20th century after application of water. Drainage installations and replacement of the offending clay-bearing materials are modifications used to circumvent potential hydrocompaction problems.

6. Tectonic movements: These movements include earthquakes and man-caused explosions which directly cause reordering and subsidence, and which commonly cause additional ground subsidence in already unstable areas. Some materials such as quick clays and quicksands lose all their cohesive strength and acquire the properties of a liquid upon being violently disturbed. Such materials can flow and envelope buildings constructed on them.

7. Liquefaction: When loose saturated soils are subjected to cyclic or impact loads, they tend to compact, thereby developing excess pore water pressures which may in turn result in complete loss of interparticle friction in the soil mass. Such a state is called liquefaction. A liquefied soil behaves like a fluid and cannot carry any shear loads. As a result, buildings can sink into a liquefied ground mass, earth slopes cannot be sustained, dams and bridges may collapse, or large landslides may occur. Liquefaction is a common phenomenon during earthquakes and it can also be triggered by strong explosions, pile driving, wave action, etc.

Ground subsidence is commonly caused by a combination of factors. Geologic conditions which are favorable for its occurrence include the presence of mines, soluble or flammable materials, oil, water or gas, windblown soils, fluent clays or quicksand, faults or fractured rocks, and good water circulation. It is imperative to recognize these potential problems *before* construction commences and to take corrective measures where they are called for.

13.2.8 Other Hazards. Geologic hazards such as avalanches and other snow and ice processes do not influence the three areas concerned and are not discussed here.

13.2.9 Conclusions. A word should be added to the preceding description of geologic hazards. Many of those described occur suddenly, while others take place over a long period of time. Almost all of these “hazardous” events are normal geologic processes and should be expected to occur from time to time. We have learned to predict and control some of these processes, but for others the best we can do is study the likelihood of their occurrence in different areas and avoid building where danger is great.

13.3 Geology and Geologic Hazards at Edwards Air Force Base, California.

13.3.1 Geology. Edwards Air Force Base is covered by rock materials of three distinct age groups (ref. 13.17). The oldest rocks are pre-Tertiary (pre-65 million years ago) granite instrusive and metamorphic units (Ig on fig. 13.10). These rocks are similar in age and composition to the Sierra Nevada Batholith. They form most of the ridges and hills within the air base boundaries.

Minor amounts of Tertiary age rocks (3 to 65 million years old) are exposed at Edwards Air Force Base (Tvi on fig. 13.10). Most of these are dikes and sills of fine-grained rock. A few volcanic flows and pyroclastics, with interbedded sediments, crop out along the eastern boundary of the base. Some bentonite layers occur within the sedimentary units. Although the dikes and sills form stable slopes, some of the slopes covered by the pyroclastic and sedimentary interbeds are unstable.

Most of the terrain within the boundaries of Edwards Air Force Base is covered with thick units of Quaternary and Recent (3 million years old) unconsolidated and weakly consolidated materials which include alluvial sand and gravel (Qa on fig. 13.10), beach dunes and bars (also Qa), playa clays (Qc), windblown sands (Qcs), and older, partly consolidated gravels (Qf). These deposits generally occupy areas of low relief.

Alluvial sand and gravel, deposited by action of flowing water, form channel and fan deposits. Wave-deposited bars and wind-deposited dunes occur along the northern “shore” of Rogers Lake. Minor clay balls occur in the wave-deposited bars. Windblown sand forms small dunes elsewhere within the base, and also covers parts of the desert floor with a thick veneer of sand.

The playa clays are mudflat facies of the alluvium. They are hard when dry but become soft and sticky when wet. Studies by Droste (ref. 13.18) found that playa clays from Rogers Lake consist of 40 to 50 percent montmorillonite and 40 to 50 percent illite. Clays from Rosamond Lake consist of 20 to 30 percent montmorillonite, 50 percent illite, and 20 to 30 percent chlorite. Although in the desert climate thorough wetting of the playas is rare, these high-montmorillonite clays are subject to severe swelling and shrinking, which should be considered when planning construction activities near the dry lake beds.

Several high-angle, northwest-trending faults have been mapped in the southern and eastern parts of the air base. They have small displacements and seem to edge granitic domal features. The faults are at present inactive.

13.3.2 Geologic Hazards. The following subsections describe the general locations of potential geologic hazards which exist at Edwards Air Force Base (fig. 13.11). On-site investigations and engineering properties tests are recommended on a location-by-location basis before initiation of any construction activities.

13.3.2.1 Earthquakes. There were no recorded earthquakes with epicenter magnitude of 4 or greater at Edwards Air Force Base or within 25 miles of it between 1910 and the present (refs. 13.19, 13.20). The base is located on a relatively stable wedge between the San Andreas and Garlock faults, both of which are less than 40 miles from the base. The proximity of these major active faults indicates regional tectonic instability. However, the known faults mapped in the eastern and southern parts of the base seem to be inactive, and earthquake hazards are judged to be negligible.

The likelihood of surface fault rupture at the Edwards Air Force Base NASA Dryden site is considered to be very remote. However, it cannot be dismissed completely because it is not presently known if any buried faults underlie the site which may belong to the group of Mojave block faults. Another risk, albeit a low one, is the possibility of sympathetic movement, including fault rupture extending to the ground surface, of these possible underlying faults in response to large motions from a great earthquake on the San Andreas fault (ref. 13.4).

Recommendations for Edwards Air Force Base Seismic Design Criteria:

It is recommended that facilities that are to be constructed on Edwards Air Force Base be evaluated for their resistance to the two following earthquakes (ref. 13.4).

1. A magnitude 8.5 event on the nearest approach of the San Andreas Fault, ~29 miles, would impose an acceleration of 0.40 g on the site with a bracketed duration of 40 s. It is suggested that a scaled trace of the N21E component of the Taft accelerogram of the 1952 Kern County earthquake is an adequate model.

2. A near-field magnitude 4.5 event from a Mojave block fault would impose an acceleration of 0.20 g at the site with a short bracketed duration of 6 s. It is suggested that the unscaled trace of the Lake Hughes No. 4 S69E component from the San Fernando Valley earthquake of 1971 be used as an appropriate model.

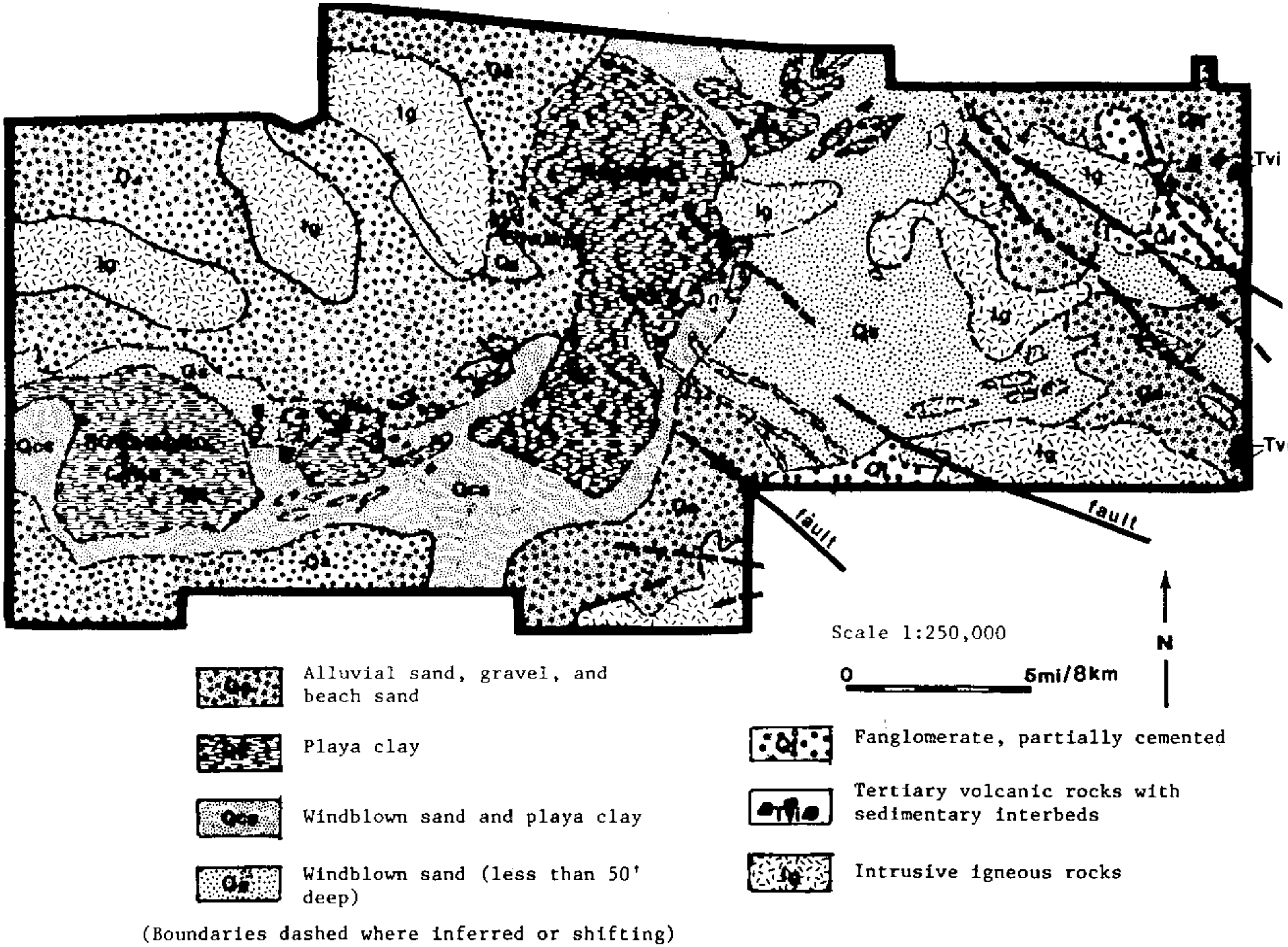


Figure 13.10 Geology of Edwards AFB, California (after Dibblee, ref. 13.17).

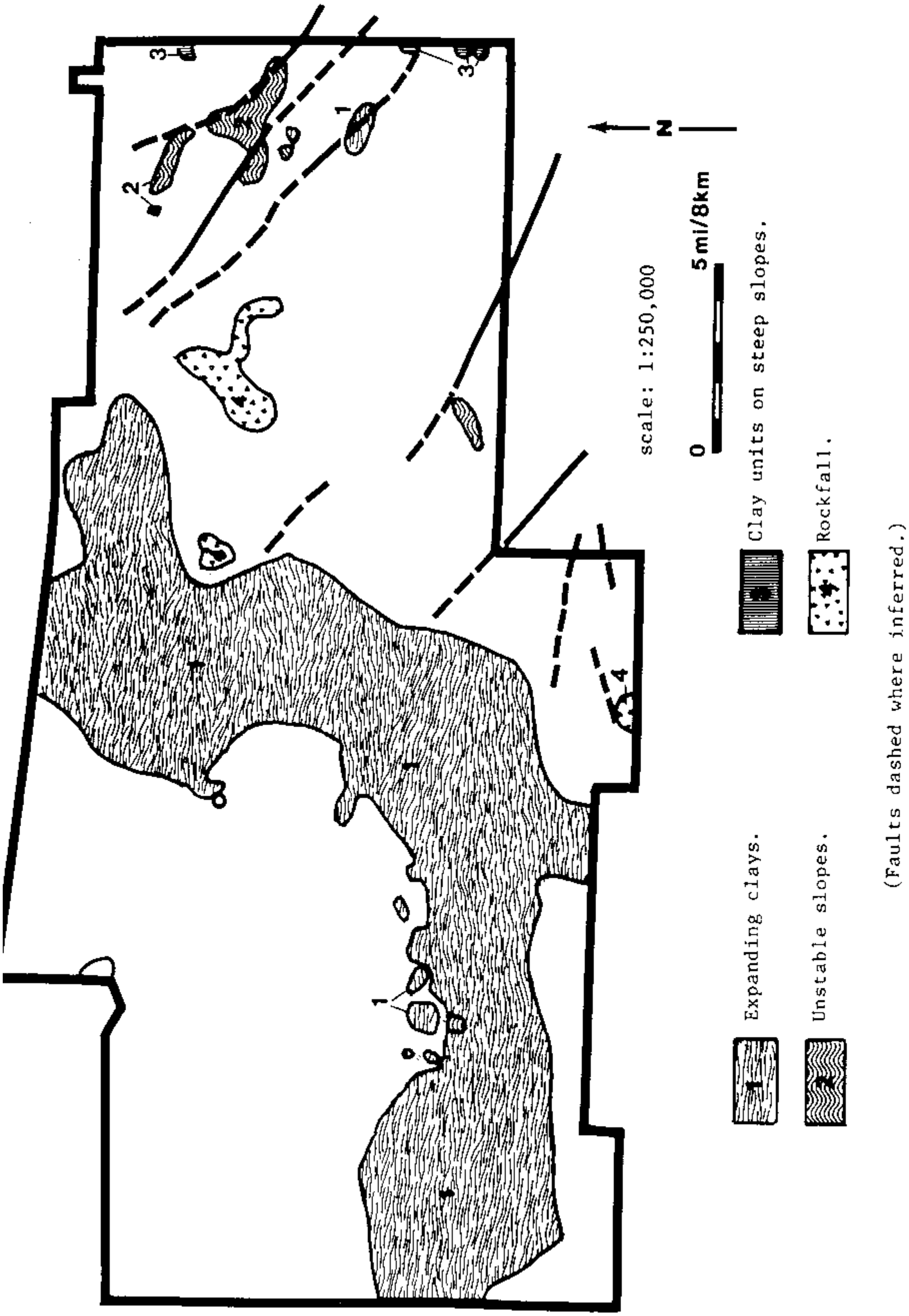


Figure 13.11 Geological hazards of Edwards AFB, California.

13.3.2.2 Slope Processes. All of the air base lies within an area designated as 1 by Radbruch and Crowther (ref. 13.21). This designation identifies areas in California which have the lowest number and volume of landslides per given area. Hilly parts within a unit 1 area may experience landslides, but because of the overall low-to-moderate relief, few problems from slope processes are expected. Some hazards may exist on steep gravel-covered slopes. The fanglomerate units that form steep slopes in the Kramer Hills, near Jackrabbit Hill, and elsewhere on the base should be considered susceptible to mass movement. Slopes covered by Tertiary pyroclastics and interbedded sedimentary layers along the eastern boundary are potentially hazardous. Rockfall problems may exist at the bases of granite cliffs.

13.3.2.3 Flooding. Except for very local flash flooding, no flood hazards are likely. Flash flooding may turn playas into shallow temporary lakes.

13.3.2.4 Expanding Ground. Careful examination of the engineering properties of the playa clays should precede construction activities. The high montmorillonite content of these clays leads to swelling and shrinking when they are alternately wet and dry. Similar caution should be exercised when dealing with the Tertiary pyroclastics and their sedimentary interbeds.

13.3.2.5 Subsidence. Localized subsidence may occur near old mine diggings. There is also the possibility of hydro-compaction in playa clays.

13.3.2.6 Conclusions. Edwards Air Force Base, though mostly underlain by granite, is 65 percent covered by Pleistocene and recent unconsolidated sand, clay, and gravel. Despite proximity of major active faults, seismic risk is low. Slopes are generally less than 10 percent, so geologic hazards resulting from slope processes are localized and probably restricted to steep slopes consisting of weakly consolidated fanglomerate.

Approximately 30 percent of the air base is covered by unconsolidated clay-rich material. The clays include a high proportion of montmorillonite and are susceptible to expansion and shrinking. However, low precipitation of the Mojave Desert region greatly reduces the potential for such problems.

In summary, Edwards Air Force Base is located in a geologically low-risk area.

13.4 Geology and Geologic Hazards of Vandenberg Air Force Base, California.

13.4.1 Introduction. Land use planning for Vandenberg Air Force Base should take into account possible danger from earthquakes, seismic waves, slope instability, floods, and burning ground. Volcanism, expanding clays and rocks, and subsidence are not expected to interfere with activities on the base.

13.4.2 Geology. Figure 13.12 is a geologic map of the Vandenberg Air Force Base area. The oldest rocks on the base, found in its northwest end, are Franciscan mafic and ultramafic igneous rocks and the sedimentary Knoxville Formation of Jurassic age. The remaining rocks, which cover the greater part of the base, are much younger, ranging in age from Oligocene to Recent. Oligocene poorly consolidated nonmarine sediments crop out near the older rocks. Miocene diatomaceous earth underlies the rest of the base and is overlain extensively by younger sediments. At most of its outcroppings, the diatomaceous earth is soft, lightweight, and porous, but resistant to weathering. It contains abundant water-soluble salts, which form an efflorescence on outcrops. This rock is a source and a reservoir for gas, oil, and tar, which have been removed in oilfields north and east of the base. Pliocene to Recent sediments are generally unconsolidated, fine-to-coarse sand and conglomerate. These sediments form terraces, fill valley bottoms, and are piled into extensive sand dunes near the coast. Sediments of Pliocene age contain hydrocarbons of Miocene derivation. Pliocene and older rocks have been extensively folded and locally faulted, probably as they were compressed during western drift of the continent (ref. 13.22).

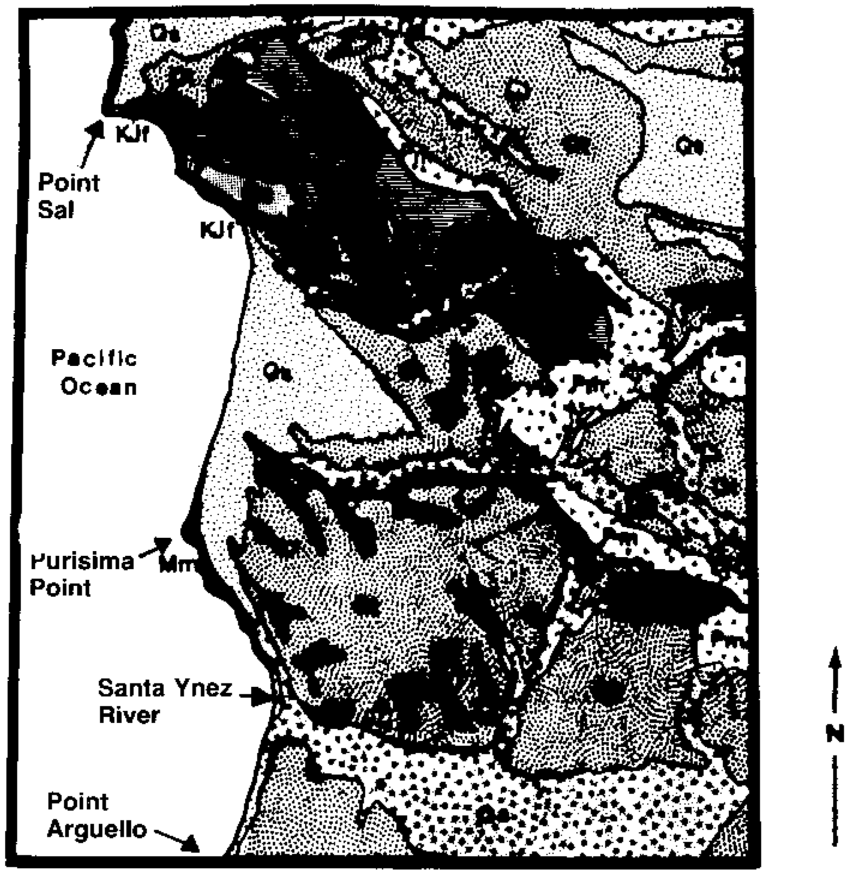
13.4.3 Geologic Hazards. The following subsections describe general locations of potential geologic hazards which exist at Vandenberg Air Force Base (Fig. 13.13). On-site investigations and engineering properties tests are recommended on a location-by-location basis before initiation of any construction activities.

13.4.3.1 Earthquakes. Although no recent fault scarps are known on Vandenberg Air Force Base, earthquakes pose an everpresent threat to it. The base is in one of the most earthquake-prone parts of the country. Between 1910 and 1971, five earthquakes with magnitude between 4.0 and 4.9 had foci within 3 miles of the base (ref. 13.23). See figure 13.14 for a depiction of earthquake epicenters around VAFB. Ground shaking has been felt on the base during many other earthquakes. Although usually of short duration, such shaking can trigger building collapse, water waves and flooding, slope movements and/or release of flammable gases. Earthquakes are a definite hazard at Vandenberg Air Force Base.

Vandenberg AFB, California (VAFB) is situated in one of the more seismically active regions of the United States and is characterized by a number of fault systems capable of generating major earthquakes. The air base is located between two physiographic regions. The Transverse Ranges Province at the south and the Coastal Ranges in the north.

Battis (ref. 13.24) presents a statistical and a nonstatistical approach in predicting maximum credible earthquakes and associated ground motion attenuation for VAFB. Battes' statistical hazard analysis, based on the historic earthquake (epicenter data) catalogue for a regional seismic risk study, gave 11 significant source regions identified within a 500-km radius of VAFB. Estimates of the maximum magnitude earthquake (M_L) possible from each source region gave results ranging from an M_L maximum of 6.1 (from the Coastal Ranges) to an 8.25 (from the Nevada Fault Zone). Maximum ground motion attenuation (acceleration, velocity, and displacement) levels were calculated at the Point Arguello site (SLC6) and are shown in Figure 13.15.

Battis also presented a nonstatistical approach in predicting maximum magnitude earthquakes and ground motion. The majority of the faults within 50 km (and faults with quaternary displacements within 100 km) of Point Arguello gave maximum credible earthquakes between 6.75 (Santa Rosa Island fault) and 8.5 M_L (San Andreas Fault Zone). See Table 13.2 which presents these maximum credible earthquake potentials using Battis' calculation of maximum displacements at the Point Arguello site (at the 90 percent confidence level). The Hosgri and San Andreas Fault Zones produce the maximum credible ground motions possible for Point Arguello.



Recent sand dunes, mobile near shore, partly anchored by vegetation inland

Recent alluvium, horizontally stratified, identical in places to Qt.

Plio-Pleistocene nonmarine terraces, unconsolidated gravel.

Pliocene loosely consolidated sand, conglomerate, rare iron oxide or calcite cement. Hydrocarbon reservoir.

Miocene marine diatomite, lower part flinty, upper soft, porous, alkaline. Hydrocarbon source and reservoir.

Oligocene nonmarine sediments.

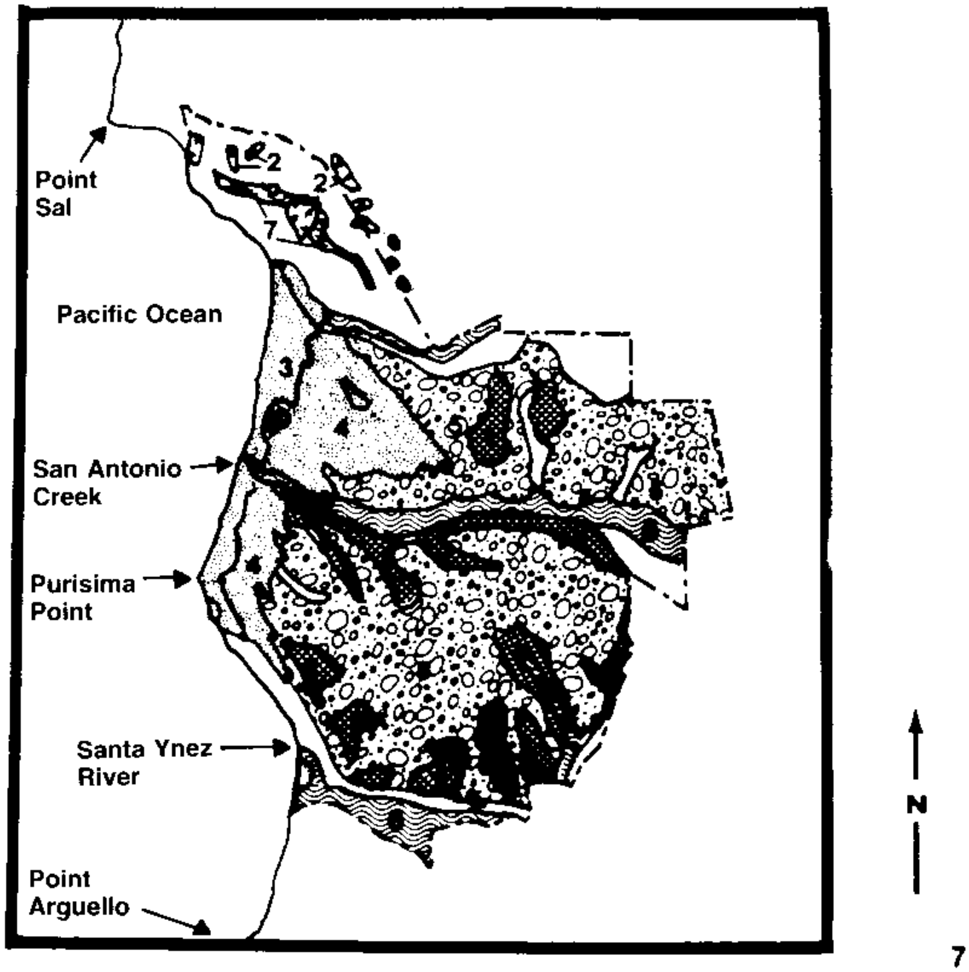
Jurassic Knoxville shale, sandstone, conglomerate.

Franciscan mafic volcanic and mafic or ultramafic intrusive rocks.

0 5mi/8km

scale: 1:250,000

FIGURE 13.12 Geology of the Vandenberg AFB Area (After Jennings, Ref. 13.22).



0 5mi/8km

scale: 1:250,000

- Gullying and resultant slope instability.
- Recent landslides.
- Active dunes. } Hazardous during Earthquakes
- Inactive dunes (anchored by vegetation). } Hazardous during Earthquakes
- Unconsolidated terrace deposits.
- Area of possible flash flooding. These areas, along with coastal areas, are also endangered by tsunamis or seiching.
- Gypsiferous, clayey rock.

FIGURE 13.13 Geologic Hazards of Vandenberg AFB, California.

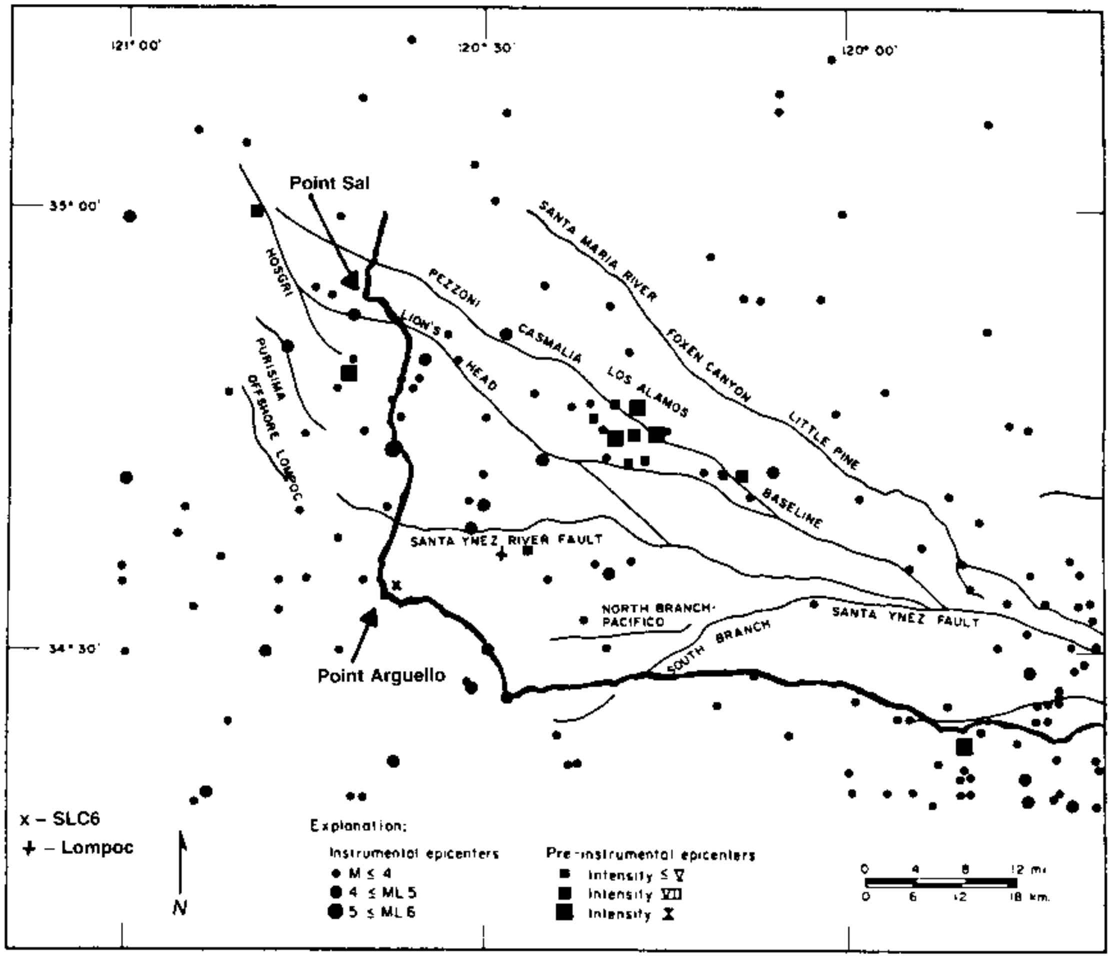


FIGURE 13.14 VAFB Area and Western Santa Barbara County, California, Earthquake Epicenters (Ref. 13.24).

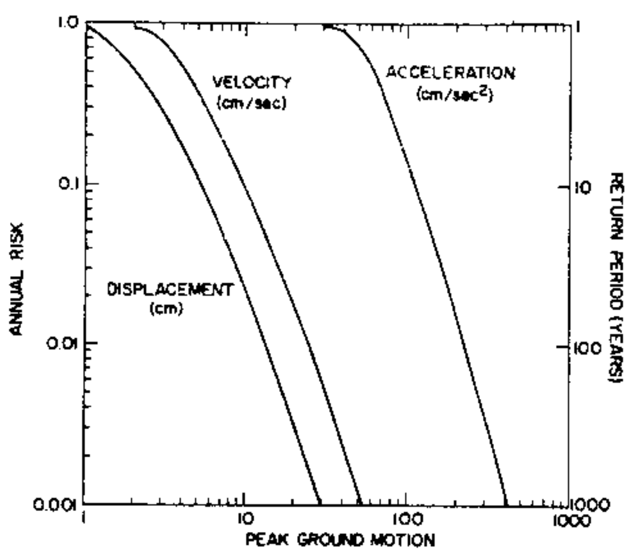


FIGURE 13.15 Annual Seismic Risk Curves for Peak Ground Motions At VAFB (SLC6), Given at The 90-Percent Confidence Level. Based on Reference 13.24 Statistical Method.

TABLE 13.2 Major Faults Near VAFB and Associated Maximum Credible Earthquakes and Ground Motions (90-Percent Confidence Level) at Point Arguello Site.[1]

Fault	Maximum Credible Earthquake (M_L)	Maximum Credible Ground Motions at Point Arguello[2,3]		
		Acceleration (cm/s^2)	Velocity (cm/s)	Displacement (cm)
San Andreas Fault Zone	8.5	387.2	91.4	64.6
Hosgri Fault Zone	7.5	678.6	110.8	54.3
Big Pine Fault	7.5			
Santa Ynez Fault	7.5			
Rinconada Fault	7.5			
Nacimiento Fault Zone	7.0			
Santa Cruz Island Fault	6.75			
Santa Rosa Island Fault	6.75			

1. Based on reference 13.24 nonstatistical method.
2. Point Arguello and Point Sal are at the extremes of maximum credible ground motion for this area. Therefore, at the Point Sal site the maximum acceleration, velocity, and displacement values of 1,288.8 cm/s^2, 200.2 cm/s, and 83.8 cm, respectively, are possible.
3. Other fault ground motion statistics were not available from ref. 13.24.

However it is felt that the majority of faults very near VAFB have maximum credible earthquake potentials of between 6 and 6.5 M_L. In actuality, from 1932 to 1975 there have been 135 earthquakes with magnitudes between 2.5 to 4.9 M_L within 50 km of Point Arguello. The largest recent event to effect the VAFB region was the 1927 Lompoc earthquake with a reported magnitude of 7.3 M_L (Modified Mercalli Intensity IX), with its epicenter appearing to lie on an off-shore fault west of Point Arguello (ref. 13.24). Figure 13.14 presents a plot of these earthquake epicenters that have occurred in western Santa Barbara County, California. Battis' work indicates that VAFB should experience a Modified Mercalli Intensity of V somewhat less than once a year, which agrees with historical data.

13.4.3.2 Tsunamis and Seiches. Seismic water waves (tsunamis) must be considered as a threat all along the shore of the Pacific Ocean. Land within 12 m of sea level is in the tsunami danger zone. (Actually, few documented tsunamis have reached that height.) Fresh-water dams should be examined to determine their strength should seiching take place. Areas on the base which could be affected by tsunamis or by seiching are given in figure 13.13.

13.4.3.3 Slope Processes. The potential for slow or fast slope changes exists in several parts of Vandenberg Air Force Base. These areas are described later and are illustrated in Figure 13.13.

a. Gullying is cutting away diatomaceous earth around the edges of Burton Mesa and San Antonio Terrace. This slow, almost continuous process has formed very steep slopes which would be unstable in a strong earthquake.

b. Several large landslides have occurred in the Casmalia Hills, in or near the north end of the base. Surface material there is obviously unstable and should be examined carefully on site before any construction.

c. Roughly one quarter of Vandenberg Air Force Base is covered by recent sand dunes. Though much of the dune area is anchored by vegetation, including windbreaks at the landward edge of the dunefield, sand blasting should be expected on San Antonio Terrace and Burton Mesa during times of high winds (see section 2 on Winds).

d. Although their surfaces are flat and nearly level, San Antonio Terrace and Burton Mesa are likely to be strongly affected by earthquake-induced surface movements because of the thick layer of unconsolidated sand and gravel terrace deposits which cover them. Shaking is highly amplified by thick, loose material, and buildings or other constructions on such material are at risk, especially if they are several stories high.

13.4.3.4 Floods. Three flood plain systems exist on the base. From north to south they are Shuman Canyon, San Antonio Valley, and Santa Ynez Valley. All three should be considered possible sites for flash flooding, especially since, during times when their rivers are dry, dune and bar sand partially block their outlets to the ocean. In addition, small dams in the Santa Ynez drainage basin could break and cause flooding during an earthquake.

13.4.3.5 Volcanic Hazards. No volcanic hazards are expected to affect this area, although tsunamis caused by distant volcanism are an always-present danger (see subsection 13.4.3.2).

13.4.3.6 Expanding Clays and Rocks. Expanding clays and rocks are not a major hazard on most of the base. Several hundred feet of gypsiferous, clayey, alkaline shale are present in the Casmalia Hills and should be avoided when locating construction sites.

13.4.3.7 Subsidence. Burning of hydrocarbon-rich layers of diatomaceous earth is well documented in historic time in the Casmalia Hills area. Burnt ground has been encountered to depths as great as 300 m in nearby oil wells (ref. 13.25). Red, hard, vesicular, scoriaceous rock ("clinker") results from this burning. However, no change in the volume of the burnt rock has been documented. Burning itself poses a threat, as it is next to impossible to stop once it has been started (by lightning or man).

13.4.4 Conclusions. Numerous potential geologic hazards exist within Vandenberg Air Force Base. Earthquakes occur from time to time, and could set off other dangerous events. Tsunamis caused by remote earthquakes or volcanism could affect the area of the base within 12 m of sea level. Seiching may pose a danger to small dams on the base. Widespread slope and surface instability is likely in the event of a strong earthquake. Blowing sand at times reduces the usefulness of some areas. Flash floods are possible in the valleys during rainy seasons. In some areas, hydrocarbon-soaked rocks have been known to catch fire. Use of different areas of the air base should take these hazards into account. True, the surface of the base is stable until rare hazard-causing events occur. But if they do, extensive destruction is possible.

13.5 Geology and Geologic Hazards at Cape Canaveral and KSC, FL

13.5.1 Introduction and Geology. Cape Canaveral, on the eastern coast of the Florida peninsula, covers an expanse of barrier bars, swamps, and lagoons between the Atlantic Ocean and the mainland. The entire Kennedy Space Center lies within 8 m of sea level. Surficial deposits on the center are roughly 30 m of Miocene to Recent shelly sand and clay and medium to fine-grained sand and silt (ref. 13.26) (fig. 13.16). These sediments overlie Eocene limestone and dolomite.

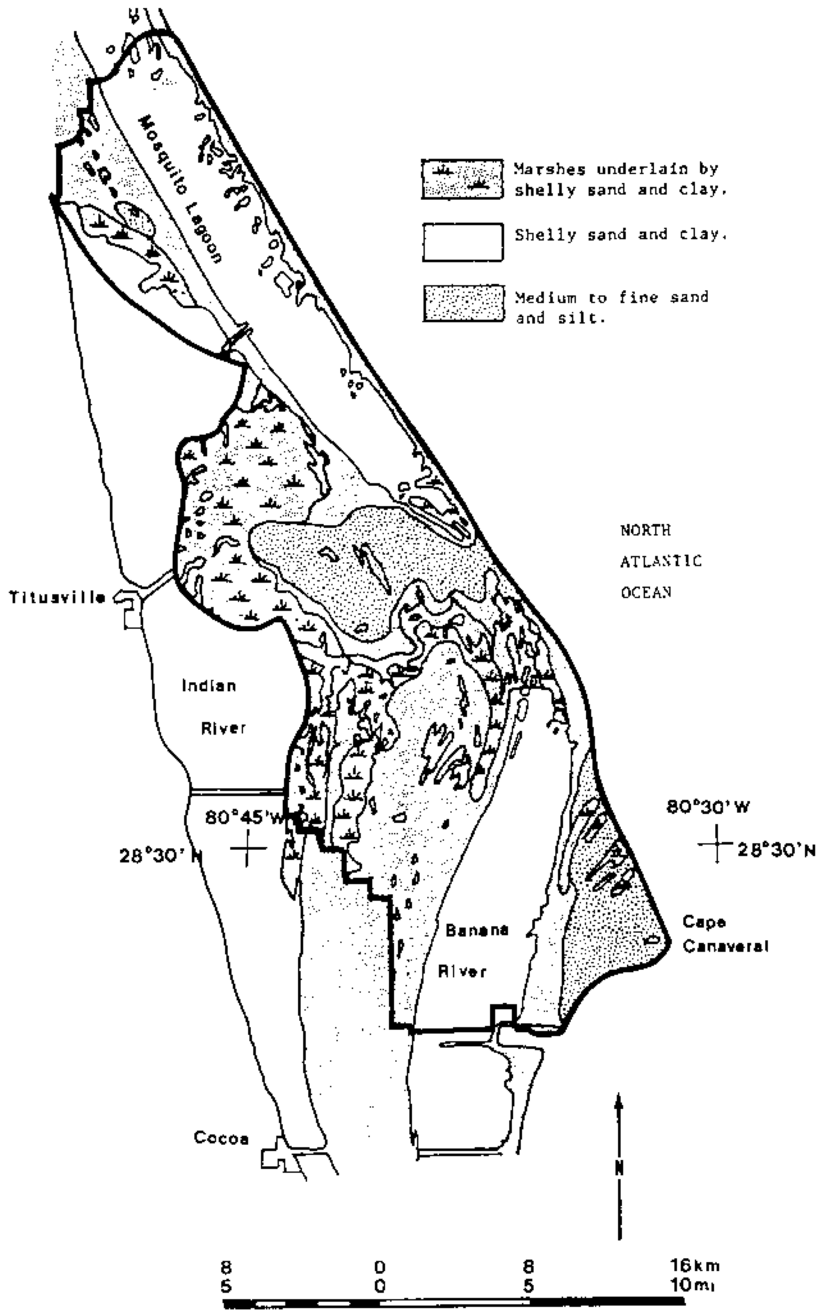


FIGURE 13.16 Geology of Cape Canaveral, Florida.

13.5.2 Geologic Hazards at Cape Canaveral and KSC

13.5.2.1 Earthquakes. Earthquakes are extremely unlikely in this corner of the United States and should not be considered a hazard.

13.5.2.2 Tsunamis and Seiches. Sea waves (tsunamis) induced by earthquakes and/or volcanism elsewhere could be a hazard to the entire space center because of its low elevation. However, tsunamis are not common in the Atlantic Ocean and, although not impossible, are considered unlikely. Nor are the lagoons and rivers likely to develop seiches.

13.5.2.3 Slope Stability. The lack of topographic relief on Cape Canaveral and Kennedy Space Center means slope stability is not a problem there.

13.5.2.4 Floods. Flooding could be a hazard to the space center if high water is brought about by hurricane winds (see sections 2 and 12 on wind and severe weather).

13.5.2.5 Volcanic Hazards. Volcanism near Cape Canaveral is unknown in recent time. The only volcanic hazards to the Cape are tsunamis caused by distant volcanism.

13.5.2.6 Expanding Soils and Rocks. Expanding soils and rocks are not a hazard to the Kennedy Space Center because of the high sand content of sediments and the consistently high humidity.

13.5.2.7 Subsidence and Uplift. Drilling results indicate the presence of caverns in the limestone and dolomite units which underlie the space center (ref. 13.26); therefore, there is potential for eventual caving. There is no apparent evidence of karst topography in the space center area, nor is collapse expected in the foreseeable future. However, test drilling should always precede building location and construction.

13.5.2.8 Conclusions. Cape Canaveral/Kennedy Space Center is a low risk area for geologic hazards. Only flooding, due to hurricanes or seismically induced waves, is considered to be of possible importance. Crucial structures which would not survive high water should be protected by dikes.

13.6 Seismic Environment. Ground support equipment (GSE), which may be subjected to a high risk potential, seismic environment, should be designed considering the geologic hazards defined in this section. The following are recommendations to consider during the design process.

13.6.1 GSE Categories and Recommendations. For seismic purposes, two categories of GSE have been established:

I. Equipment that can inflict structural damage on the space shuttle vehicle (SSV) elements during and after a seismic event by its operation or by its failure to operate.

II. Equipment located in close proximity to the SSV elements that can cause major structural damage due to support failure or physical contact with the integrated SSV or SSV elements.

All GSE elements should remain integrally constrained in their packages. The equipment should not be allowed to separate from the unit and become missiles. This recommendation does not include equipment which is already separated from SSV elements by strong physical barriers, such as walls or enclosures sufficient to prevent equipment contact with SSV elements.

13.6.2 Types of Design Analyses. Recommendations for typical dynamic or static analyses follow.

13.6.2.1 Dynamic Analysis. A rigorous dynamic analysis should be made to demonstrate that the equipment and its supporting mechanism/structure will withstand, without collapse or excessive deflection, the design loads induced in the system by a major seismic event. The effect of such an event on the system can be determined using the GSE design response spectra for major seismic events at Vandenberg Air Force Base shown in figure 13.17. The design loads should equal the root-sum-square (RSS) of the modal responses, where natural frequencies are determined by modal analysis and whose damping values are estimated by damping analysis, or by similarity to structures whose damping has been measured under actual or simulated earthquake motion.

13.6.2.2 Static Analysis. The following criteria are recommendations for designing GSE for seismic resistance:

1. GSE weighing less than 100 lb should have restraints to resist a horizontal force of x1.5 equipment weight from any direction applied to its center of gravity.

2. For GSE weighing between 100 and 1,000 lb, the following equation can be used to determine the recommended restraints:

$$F = ZKCW \,, \tag{13.1}$$

where

F = equivalent static lateral force in pounds applied at the center of gravity

Z = seismic probability coefficient (no units), where Z = 1.5 for high-loss potential equipment (damages SSV element), Z = 1.0 for low-loss potential equipment (damages GSE only)

C = seismic force coefficient (no units)

K = coefficient based on building type (no units)

W = weight in pounds of item under consideration.

C may be calculated using the following equation:

$$C = (C_s)\,(A_h)\,(MF) \,, \tag{13.2}$$

where

C_s = soil constant (no units) = 2.25–0.125 f_b = 1

f_b = allowable soil bearing value in kips per square foot (see Geophysical Investigation Supplement for VAFB Station Set V23 (VCR-77-067 of 20 January 1977)
(1 kip = 1,000 lb))

A_h = design acceleration = 0.10+0.15 (h/h_t)

h = height of equipment in building above building base

h_t = height of building.

Now, MF = magnification factor (no units)

$$= \frac{1}{\sqrt{[1-(T_a/T)^2]^2 + [0.04\,T_a/T]^2}}\ , \tag{13.3}$$

where

T_a = period of item under consideration in seconds

T = period of building in seconds

(for graphical solution to equation see figures 13.18 and 13.19).

The building characteristic constants for the mobile service tower (MST), the payload changeout room (PCR), and the access tower (AT) are shown in table 13.3. For equipment in contact with the soil, buried in the soil, or supported by footings, pedestals, or slaps supported by soil, use the following coefficients: K = 1.00 and C = 0.15.

3. Also recommended is that items weighing more than 1,000 lb be subjected to dynamic analysis. Items weighing more than 1,000 lb and having a ratio of 4 to 1 or greater between structural strength of tie down and limit load, as defined in paragraph 2, are exempt from dynamic analysis.

Equipment that is to be in use for not longer than 8 hours in close proximity to, or supporting SSV elements, are exempt from these requirements.

Equipment that is mounted on casters or wheels should have lockable casters/wheels and be rigidly tied to primary or substantial secondary structure.

TABLE 13.3 Building Characteristic Constants.

	K	h (ft)	T (s)
MST	0.8	275	1.23
PCR	0.8	160	0.93
AT	0.8	192	0.61

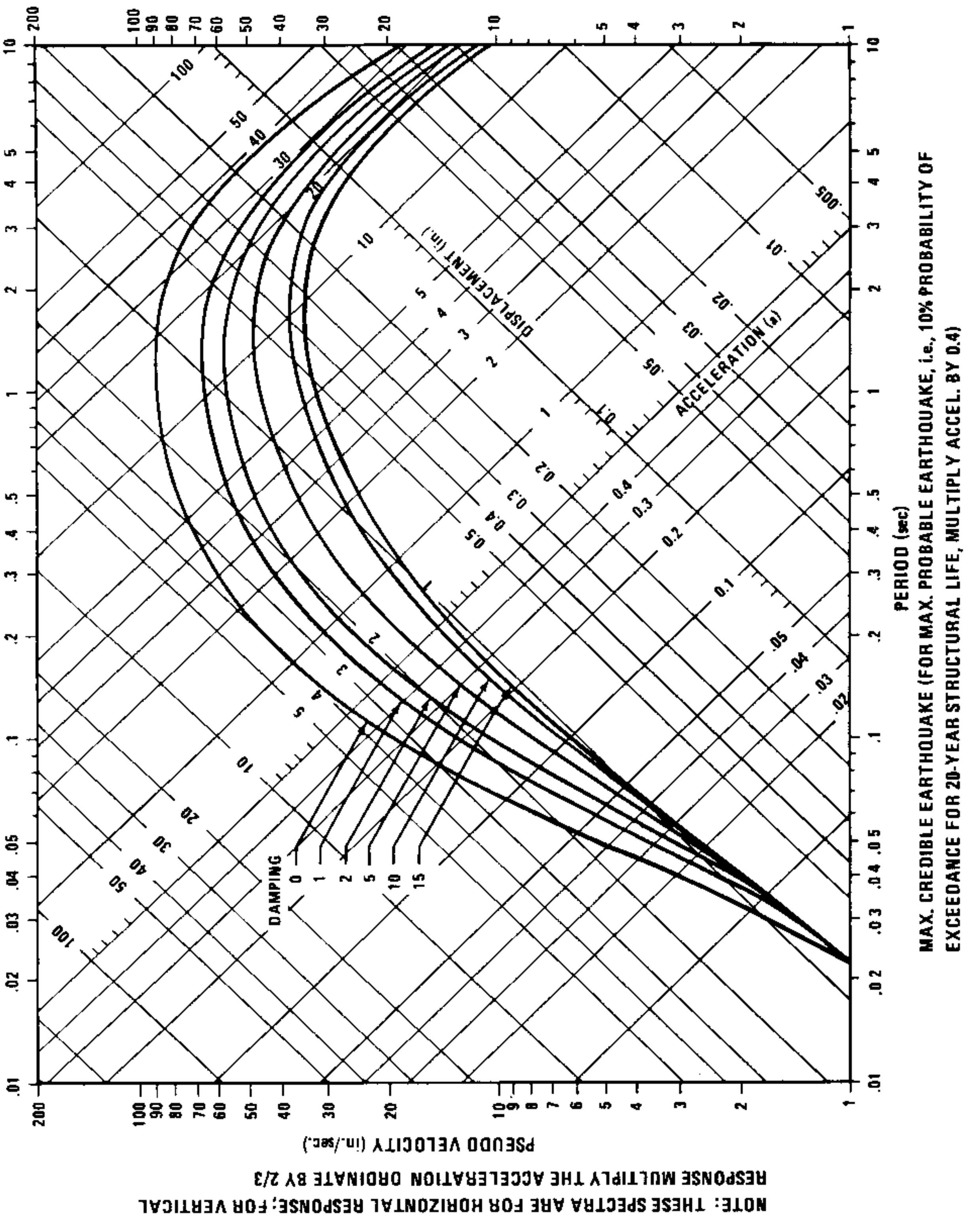


Figure 13.17 0.70E elastic design spectra for strongest potential vibratory ground motion.

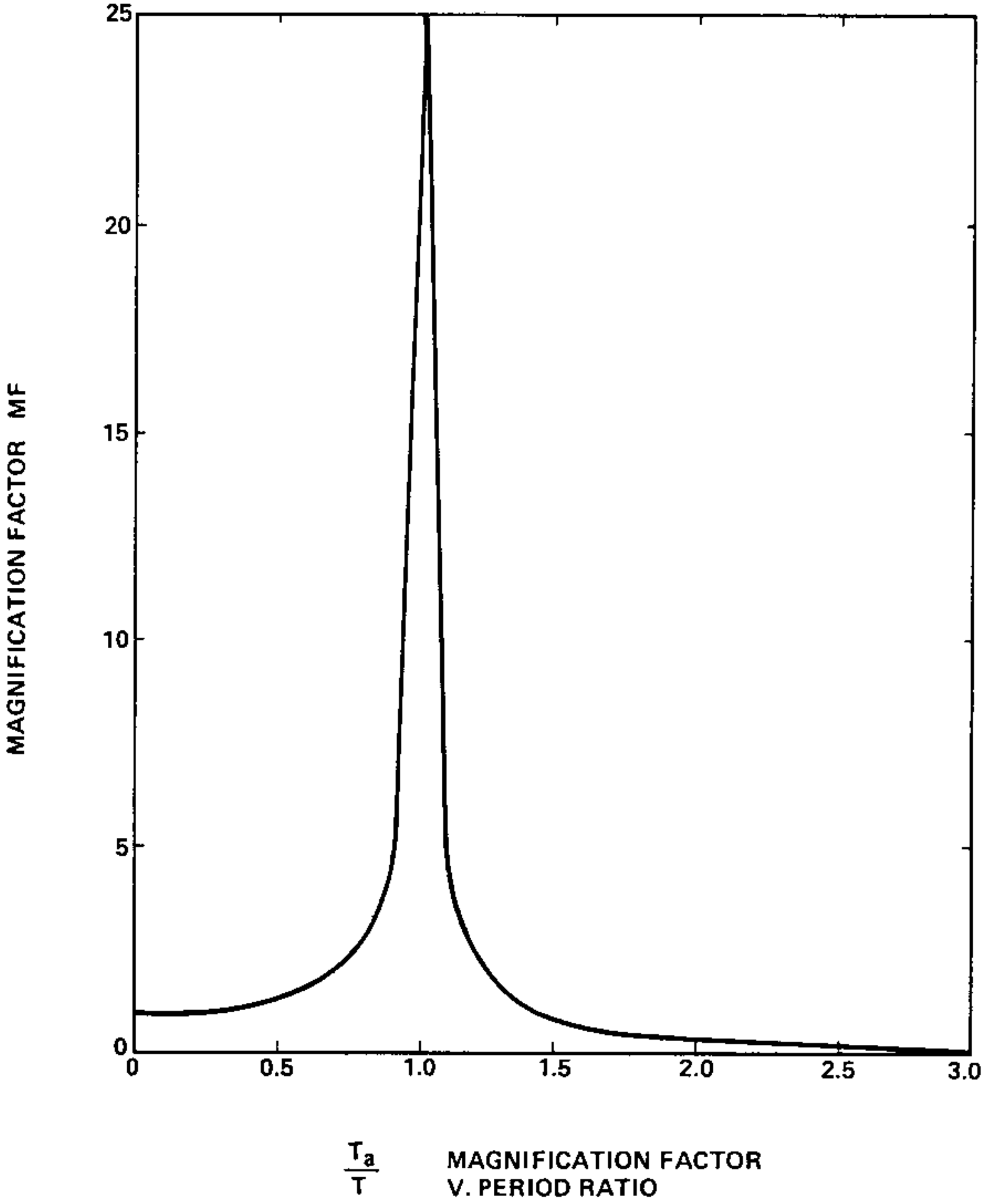


FIGURE 13.18 Magnification Factor Versus Period Ratio.

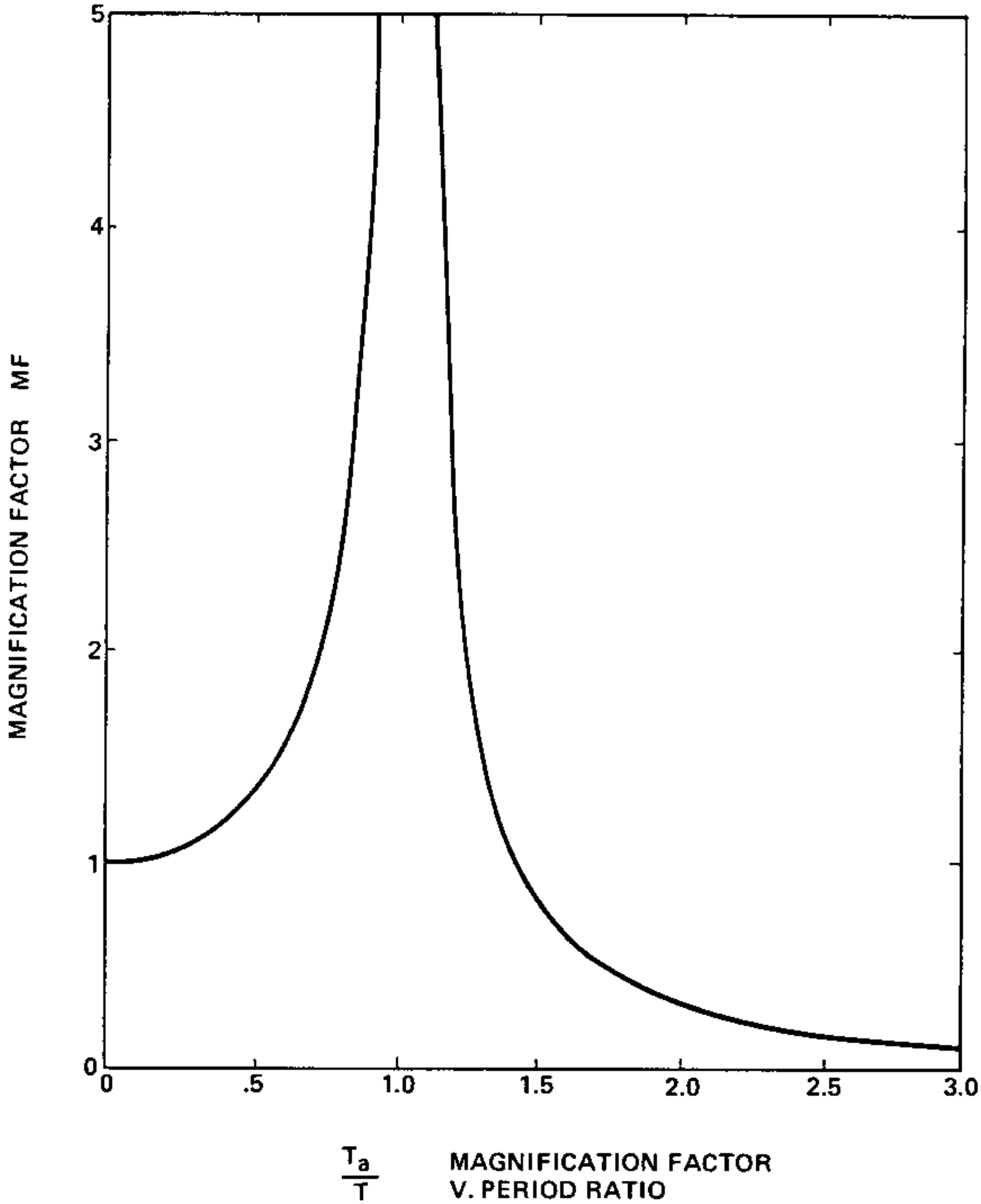


FIGURE 13.19 Magnification Factor Versus Period Ratio.

REFERENCES

13.1 Van Dorn, W.G.: “Source Mechanism of the Tsunami of March 27, 1964.” Alaska: Coastal Eng. Conf., 9th, Lisbon, 1964 Proc., pp. 166–190, 1964.

13.2 Stein, R.S. and Yeats, R.S.: “Hidden Earthquakes.” Scientific American, pp. 48–57, June 1989.

13.3a Algermissen, S.T.: “An Introduction to the Seismicity of the United States.” Earthquake Engineering Research Institute Monograph, 1983.

13.3b Algermissen, S.T., and Hopper, M.G.: “Estimated Maximum Regional Seismic Intensities Associated With an Ensemble of Great Earthquakes That Might Occur Along the New Madrid Seismic Zone, East Central United States.” Misc. Field Studies Map MF-1712, U.S. Geological Survey, 1984 (reprinted 1990).

13.4 Cousineau, R.D., et al.: “Investigation of Seismicity and Related Effects at NASA Ames-Dryden Flight Research Facility, Computer Center, Edwards, California.” NASA CR-170415, November 1985.

13.5 Krinitizsky, E.L., and Chang, F.K.: “Earthquake Intensity and the Section of Ground Motions for Seismic Design.” Corps of Engineers Waterways Experiment Station, Misc. Paper S-73-1.

13.6 Bonilla, M.: “Surface Faulting and Related Effects.” In Earthquake Engineering, Prentice-Hall, 1970.

13.7 Greensfelder, R.W.: “Map of Maximum Bedrock Acceleration From Earthquakes in California.” California Division of Mines and Geology, Map Sheet 23, 1974.

13.8a Algermissen, S.T., et al.: “Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States.” U.S. Geological Survey, Open File Report 82-1033, 1982.

13.8b Algermissen, S.T., et al.: “Probabilistic Earthquake Acceleration and Velocity Maps for the United States and Puerto Rico.” Misc. Field Studies Map MF-2120, U.S. Geological Survey, 1990.

13.9 Working Group on California Earthquake Probabilities, U.S. Geological Survey Open File Report No. 88-398, 1988.

13.10 The Loma Prieta Earthquake of October 17, 1989, U.S. Geological Survey pamphlet, 1989.

13.11 Ruhe, R.V.: Geomorphology. Houghton Mifflin Co., Boston, Mass., pp. 99–123, 1975.

13.12 Sharpe, C.F.S.: “Landsides and Related Phenomena.” New York, Columbia University Press, 1938.

13.13 Mullineaux, D.R.: “Preliminary Map of Volcanic Hazards in the Conterminous United States.” U.S. Geological Survey, Misc. Field Inv. MF-786, scale 1:7,500,000, 1976.

13.14 Bolt, B.A., et al.: “Geologic Hazards: New York.” Springer-Verlag, 328 pp. (Chapter on evaluation of volcanic hazards), 1975.

13.15 Rogers, W.P., et al.: “Guidelines and Criteria for Identification and Land Use Controls of Geologic Hazard and Mineral Resource Areas.” Colo. Geol. Survey Special Pub. No. 6, pp. 68–76, 1974.

13.16 James, D.E., Jr. and Holtz, W.G.: “Expansive Soils—The Hidden Disaster.” Civil Eng., 43, No. 8, 1973.

13.17 Dibblee, T.W., Jr.: “Geology of the Rogers Lake and Kramer Quadrangle.” U.S. Geol. Survey Bull. 1089-B, pp. 73–139, 1960.

13.18 Droste, J.B.: “Clay Minerals in the Playa Sediments of the Mojave Desert, California.” California Div. Mines and Geol. Special Report 69, 1961.

13.19 Mortan, D.M.: “Geologic Hazards in Southwestern San Bernardino County, California.” California Div. Mines and Geol. Special Report 113, 1976.

13.20 Real, C.R., et al.: “Earthquake Epicenter Map of California, 1900–1974.” California Div. Mines and Geol. MS 39, 1978.

13.21 Radbruch, D.H. and Crowther, K.C.: Maps showing areas of estimated relative amounts of landslides in California. U.S. Geol. Survey Misc. Geol. Inv. Map 747, 1973.

13.22 Jennings, C.W.: Santa Maria Sheet, Geologic Map of California. California Div. of Mines, 1:125,000, 1959.

13.23 Fife, D.L., et al.: “Geologic Hazards in Southwestern San Bernardino County, CA.” California Division of Mines and Geology Special Report 113, plate 7, Earthquake Epicenters in Southern California, 1910–1917, 1976.

13.24 Battis, J.C.: Seismic Hazards Estimation Study for Vandenberg AFB. AFGL-TR-79-0277, AFSIG No. 418, November 14, 1979.

13.25 Arnold, R. and Anderson, R.: “Geology and Oil Resources of the Santa Maria Oil District, Santa Barbara County, California.” U.S. Geol. Survey Bull. 322, map (1:125,000), 1907.

13.26 Scott, T.M.: Orlando Sheet, Environmental Geology Series. Florida Geol. Survey MS 85, 1978.